# Charles University in Prague

## Faculty of Social Sciences
Institute of Economic Studies


MASTER'S THESIS

# Hedge Effectiveness in Copper Futures Market: Case study for "Erdenet" Mining Co.Ltd in Mongolia


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Academic Year: **2014/2015**

## Declaration of Authorship

The author hereby declares that he compiled this thesis independently, using only the listed resources and literature, and the thesis has not been used to obtain a different or the same degree.

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Prague, May 14, 2015

Signature

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Last but not least, I am truly thankful to my family for their support and I dedicate this thesis to my baby son Zorigt.

# Abstract

The objective of the thesis is to analyze the copper futures market in London Metal Exchange (LME) and to recommend appropriate hedging strategy in copper futures market to the Erdenet Mining Corporation in Mongolia. It uses daily official settlement copper prices of LME in the spot and 3 month futures markets from 2000-2014. Initially, we use cointegration test and ECM to investigate the copper market efficiency. Then OLS, ECM, GARCH, EGARCH and ECM-GARCH models are employed to compute different optimum hedge ratios. Finally, the hedge effectiveness is measured based on minimization of the value of AIC and SBIC. Our result indicate that copper futures market is inefficient. Hedge effectiveness comparison concludes that ECM model gives the best hedging performance. However, ECM-GARCH is accounted to be the best model for hedging strategy since it captures the time-varying conditional heteroscedasticity to ECM model.



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# Acronyms

**EMC** Erdenet Mining Co.Ltd

**LME** London Metal Exchange

**HE** Hedge Effectiveness

**OHR** Optimum Hedge Ratio

**EMH** Efficient Market Hypothesis

**MV** Minimum Variance

**OLS** Ordinary Least Square

**ECM** Error Correction Model

**GARCH** General Autoregressive Conditional Heteroscedasticity

# Master’s Thesis Proposal

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|---|---|
| **Author** | Bc. Baigali Khurelbaatar |
| **Supervisor** | PhDr. Ladislav Kristoufek Ph.D. |
| **Proposed topic** | Hedge Effectiveness in Copper Futures Market: Case study for ”Erdenet” Mining Co.Ltd in Mongolia |

**Motivation** Mongolian economy is heavily dependent on the mineral exports. In 2013, the share of mineral exports is 88% out of total exports that amounts to almost one-third of the government revenues and contributes 22% to the country’s GDP. The exchange rate volatility is highly affected by the world’s copper and gold price movement. Erdenet Mining Co.Ltd (EMC) is one of the biggest copper mining, copper processing factory in Asia and the main exporter of Mongolia. It started the operation in 1978. Since then, EMC determines it’s copper price by LME without participating in Copper Futures Market. At this moment, only Central Bank of Mongolia hedges Mongolia’s gold exports against unfavorable price movement in futures market. The question is: Why does EMC avoid installing risk instruments and insurance schemes since it contributes almost half of the national export? It not only hedges against falling copper price. Also it reduces the country’s exposure. This thesis will focus on the hedging problems faced by the EMC. By using historical data obtained from LME, I will try to show that market-based insurance scheme is effective in copper futures market.

**Hypotheses** For the hypothesis testing, I will consider Futures Market as it is installable in the short-run.

Hypothesis 1: Efficiency of Copper Futures Market The copper futures market in LME is efficient and unbiased estimator of future copper spot prices. If this hypothesis is rejected, futures market in LME can be one of alternative choice for the EMC to hedge against unfavorable price movements.

Hypothesis 2: HE of Optimum Hedge Ratio (OHR) regarding to different models. Above two hypotheses will give answer for the main question of the thesis " To hedge or not to".

Hypothesis 3: Linkages between SHFE and LME EMC exports approximately 60% of the all products to China and uses LME's copper price. Main intention of this hypothesis is to find out which Metal Exchange makes the first move on price movement and which follows. This hypothesis may give accurate answer for "Where and When to hedge?"

**Methodology** Hypothesis 1- Can be tested by OLS and co-integration between spot and futures prices. ADF test on regression residuals, VAR error correction mechanism and Error-Correction Model (ECM). In order to test it, I will use daily copper spot prices and futures contract prices with different maturities and it can be obtained from LME.

Hypothesis 2- Each econometric model will give us different OHR but we need the highest OHR. To get OHR, I will use the VAR, the vector error correction and GARCH model.

Hypothesis 3- Linkages in price, return and volatility across the two markets can be obtained by using Co-integration Methodology, ECM and GARCH. For this hypothesis, I will import additional data from the SHFE.

**Expected Contribution** Mongolian derivatives market is in its infancy. Lately, young economists explored some researches on Mongolian risk management, insurance schemes for currency, exchange rate or commodity price but it is very limited. For the EMC, there are a very few studies that suggest hedging methods but all of them are verbal suggestions and none had empirically tested yet. I hope my study will expand EMC's literatures and if the empirically tested result is same as I expected, it can be applied in practice

## Outline

1. Introduction
2. Related research and theories
3. Hypotheses and research questions
4. Data and Methodology
5. Analysis and empirical results
6. To hedge or Not to Hedge

7. Conclusions

## Core bibliography

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# Chapter 1

# Introduction

The investigation of international commodity market is an important topic not only for researchers, but also for commodity producers as well as consumers and for portfolio managers. Christian (2004) states that commodity market itself is a very unstable market and substantial even dramatic price volatility emerges the market. Reasons can be numerous such as non-diversifiable homogeneous products, non-predictable natural catastrophes, exploitation of new resource, international as well as national political and economic pattern changes, global war, metal industry's structural changes. D.Lien & Yang (2006) empirically shows that price adjustment in commodity market is more sensitive to negative noises than the positive one that leads to higher volatility in market thus such activity in the market creates shaky position for the producers of the commodity. So how producers can ensure the highest price until the delivery of their products? This can be done through commodity futures, options, short sales and warrants markets. This process is known as hedging strategy. In this thesis, we go through the Efficient Market Hypothesis (EMH) and hedging strategy in copper futures market in London Metal Exchange (LME).

Copper futures contracts are considered to be less costly method for market participants and it has the minimum possible restrictions and rules in LME. Before trading in commodity exchange market, one should ask himself: Is the market efficient and reflect all available information to the price? Fama (1965a;b) and Samuelson (1965) were among the first to observe the market efficiency from two different approaches independently. Both studies came with same conclusion and suggest if the market is efficient, changes in prices will be unpredictable and there will be no arbitrage opportunities. Large body of literature cover various procedures and investigate the EMH for different type of markets. The efficiency of copper futures market in LME is examined by number of researchers such as Goss (1981), MacDonald & Taylor (1988a;b), Canarella & Pollard (1986), Kenourgios & Samitas (2004), Otto (2011) and others. The most of the studies could not support the EMH in copper futures market in LME and more details are covered in literature review.

So lets say the market is inefficient and there is a forecasting power of spot prices from futures prices. Then how producers should hedge against existing risk premium in copper futures market and reduce the potential risk of price movement? Researchers suggest various types of methods to hedge in commodity market and all of them differ based on model as well as market specification. Basically, valuing Optimum Hedge Ratio (OHR) and Hedge Effectiveness (HE) is the first step for making hedging decision. Most of the models are based on the Minimum Variance (MV) approach due to its optimality in both efficient and inefficient market and Jonhson (1960) was the first to introduce this model in the literature. Thesis is concentrated on market risk premium to compute OHR and distinguish risk premium into 3 parts: no risk premium, constant risk premium and time-varying risk premium. Many models are developed to capture the risk premium in OHR and among them OLS, ECM, VECM, family of ARCH models, DCC models are the most commonly used.

In this research which relates to the literature of hedging in copper futures market, author uses methodology used in studies of Ranganathan & Ananthakumar (2014) and Kenourgios & Samitas (2004) to measure market efficiency. Methodology of computation of OHR and HE are mainly based on the studies of Dlamini and Kenourgios *et al.* (2008). First of all, author tries to prove that copper futures market is inefficient. Then she employs OLS, ECM and GARCH models based on types of risk premium to compute different OHR and compare the results.

The aim of this thesis is to give important and reliable information about current copper futures market situation in LME to the EMC. EMC is a copper producing company in Mongolia that trades its production in spot market of LME since it's beginning of operation. The company faces potential loss when there is downside risk of price development in LME. At this moment, it has no hedging instruments in such market and remove small part of potential risk through manufacturing process management. Final output of this research is to introduce appropriate hedging strategy to the EMC that can be applied in practice.

The thesis is structures as follows: Chapter 2 provides all necessary terms about commodity market. First of all, a short description on Mongolian commodity and derivative markets are given for readers to have better understanding of Mongolian economy. Then author gives the most important terms about future contract property and trading in LME. Chapter 3 introduces overview of existing literature. This chapter is divided into 2 main parts: EMH and Hedging in Copper Futures Market. Chapter 4 describes the model choice and its methodology for the hypotheses. Also readers go through the data analysis and diagnostic tests in this chapter. Chapter 5 provides empirical analysis of the EMH, computations of OHR and appropriate interpretation of statistical results are given. Finally, chapter 6 gives the most important finding that can be recommended to the EMC and can be applied in practice. Chapter 7 summarizes all research done in this thesis and concludes.

# Chapter 2

# Commodity Market Description

In this chapter we go through short description on commodity market's segments and futures contract traded in LME. By this way, we can have a complete picture of the structure of this market. Additionally, brief overview of Mongolian commodity and derivatives market will be provided with the market statistics.

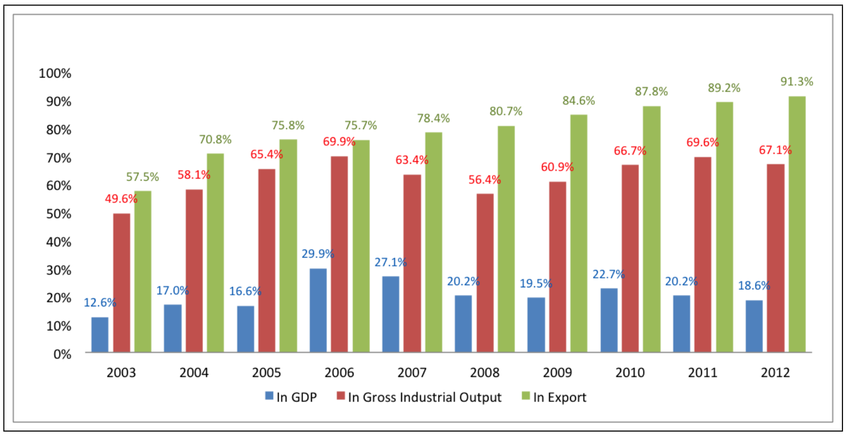
## 2.1 A Short Description on Mongolian Commodity and Derivative Markets

Commodities refer to raw material used in manufacturing goods and services. Since commodity prices, producers' and consumers' income is fluctuating frequently, commodity market is considered as an unstable market. Before trading on such market, one should consider efficient trade and the best way to do so is trade through derivative markets. When nation's economy heavily depends on commodity export, effective hedging strategy must be applied against unfavorable price development. Mongolia is natural resource rich country that mineral exports contribute almost 90% out of total export and it amounts one-third of the government revenues (more in Figure 2.1).

Nonetheless, Mongolian derivative market is in its infancy and only Central Bank of Mongolia hedges gold export in futures market. But big mining corporations find hedging is impossible or too costly and trade in spot market. At this moment, Mongolia only has a spot forex market and almost no interbank market.

Until global financial institution ING had entered into the Mongolian financial market in 2012, no other international investment bank had a presence

Figure 2.1: The role of mining sector in overall Mongolian economy




*Source:* Mongolian Statistical Information Service.

on the Mongolian financial market. Right after ING entrance, Goldman Sachs bought 4.8% stake in Trade & Development Bank in Mongolia. The most important reason for recent international financial inflow is the resource boom in Mongolia. Mongolian GDP growth was expected at 17% in 2012 and 15% in 2013 thanks to the start of copper production of the "Oyu Tolgoi" mine and "Tavan Tolgoi" mine. According to Brook Hunt(2014) long-term analysis, Mongolia had contributed 14.6% of Asian, 0.72% of world's copper resources in year 2012 and 19.65% of Asian, 1.12% of world's copper resources in year 2013. Next 15 years long-term forecast is included in Table 2.1 and such increase is due to start-up of "Oyu Tolgoi" mine.

Table 2.1: Mongolian copper mining production forecast

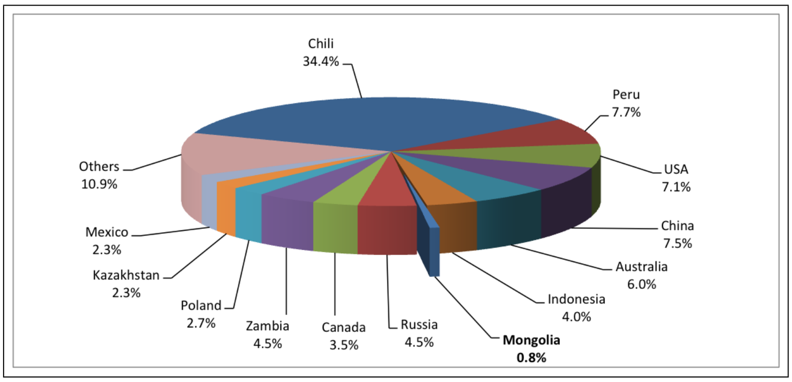
| Index | 2013 | 2014 | 2015 | 2016 | 2017 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|---|
| Mongolian capability | 202 | 288 | 321 | 321 | 320 | 336 | 304 | 284 |
| Asian capability | 1028 | 1210 | 1534 | 1710 | 1227 | 1370 | 1295 | 1127 |
| Mongolian share of Asia | 19.65% | 23.80% | 20.93% | 18.77% | 26.08% | 24.53% | 23.47% | 25.20% |
| World capability | 18096 | 19708 | 21377 | 21690 | 21358 | 19794 | 16185 | 13336 |
| Mongolian share of world | 1.12% | 1.46% | 1.50% | 1.48% | 1.50% | 1.70% | 1.88% | 2.13% |

*Source:* Brook Hunt long-term analysis, 2014.

At this moment, "Tavan Tolgoi" mining contract is not signed by the government and is still in discussion. It's resource is estimated to be 5 times bigger than "Oyu Tolgoi" mine. With these two very large mining projects, Mongolia economy faces unique opportunities from commodity revenues but it can also bring long-term depression by increasing macroeconomic volatility. Mongolian tughrik exchange rate is very volatile and one of the biggest driving forces is the world's commodity price movement. In 3 years, Mongolian currency depreciated by 34% against US dollars that resulted to high volatility in inflation and largely reflected on food prices' volatility. Isakova *et al.* (2012) states that resource boom not only brought unique opportunity but also brought long-term depression in Mongolia. To avoid further depression, Mongolia has to be very careful with applying new economic policies without harming other sectors. Improving Mongolian derivative market and supporting mining corporations to hedge in commodity futures as well as options markets could be helpful tool to ensure low volatile exchange rate.

EMC is one of the 10 biggest copper mining, copper processing factory in allover world and the main exporter of Mongolia. It started the operation in 1978 and processes approximately 0.8% of world copper resources in year 2012 (Figure 2.2).

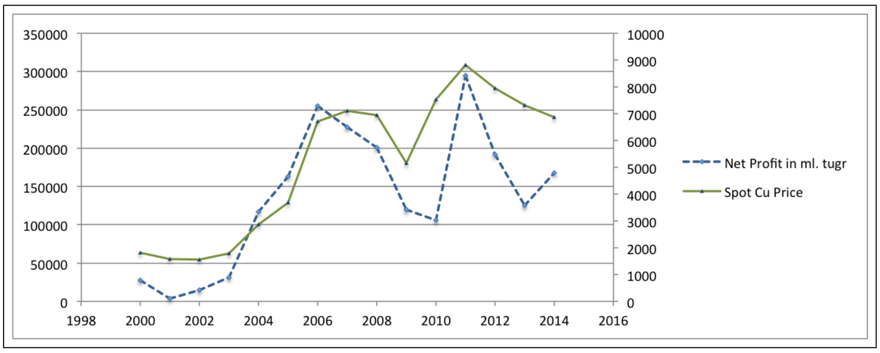
Figure 2.2: Erdenet mining corporation's contribution to the world's copper market




*Source:* Mongolian Statistical Information Service.

For it's entire operating period, EMC determines it's copper price by LME without participating in derivative market. Since EMC doesn't use any market-based insurance scheme, unfavorable commodity price movement is hedged through manufacturing process management and long-term bilateral contracts. Being more specific on manufacturing process management, the average grade of copper ores is below 0.6% copper, with a proportion of ore minerals being less than 2% of the total volume of the ore rock. EMC makes small changes on these grades to avoid facing potential loss regarding to price drop on LME. This hedging strategy is very old fashioned or it can be explained as opportunity cost. Below figure illustrates the relationship between EMC's yearly net profit and yearly average spot price of LME.

Figure 2.3: Relationship between net profit of the company and spot price in LME




*Source:* Author's computation

In Figure 2.3, the left-hand side axis is expressed in million tughrik, corresponds to the net profit of the EMC and the right-hand side axis is expressed in USD, corresponds to the spot copper price in LME. As shown in Figure 2.3, EMC's operation is very limited by the LME activities. Market volatility itself has an immense influence on company's net profit and small negative changes in spot price brings big amount of loss to the company. In year 2008, yearly spot price is dropped by 2% that caused net profit to be decreased by 12%. Major drop of the net profit could be caused by other forces such as forex risk, currency risk or Mongolian economic situation. But in Figure 2.3, clear linkage is found between company's net profit and market price. Also manufacturing processing management doesn't ensure the company's profitability and it can be concluded that EMC operation is unstable due to high market volatility. Since there are number of impacts on company's operation including resource boom, currency depreciation and forex risk, EMC must start looking way to avoid at least commodity price risk and how to manage it. Thus further analyses are concentrated on commodity price risk.

## 2.2 Futures Contract Trading in LME

Substantial even dramatic price volatility emerge world commodities market. This happens as a result of non-diversifiable homogeneous products and non-predictable natural catastrophes or new development of resource. Additionally, international as well as nation's politics regarding to export controls, global wars, economic patterns changes, currency devaluation, metal industry's structural change etc. may have strong impact on price fluctuations. There are four types of impacts on price movements: day-to day market expectation, world supply and demand on commodity, permanent changes in special countries or regions and long-term price change resulted from natural disaster. Price risk management may only manage first two impacts. To effectively ensure price risk, producers always try to be in situation where future contract price is not below the cash price. Possible hedging strategies can be done through Futures, Options, Short Sales and Warrants. Options, short sales and warrants effectiveness will not be discussed, since the thesis is concentrated on the futures market The LME began it's operation in 1877 and today it is the world's premier non-ferrous metals' market that offers futures and options contracts for precious metals and they offer 3 different services:

- Pricing of commodity: Each day LME announces a set of official prices used by the worldwide industry as the basis for contracts for physical materials to provide regulations, transparency for trading of futures and option contracts.

- Risk management: LME offers the opportunity to hedge commodity price risk through its trading members.

- Physical delivery: As a market of "last resort", industries can use of LME's delivery option to sell excess stock or use as a source of materials in times of over supply or shortage. But physical delivery occurs rare in reality.

The basis for LME price quotations is US Dollars and the cash (2 business days from date of contract), 3 months price are the most active basis. Also there are 3 to 6 months basis and 7 to 63 months basis. LME offers traded option contracts based on each of these futures contracts. Martinot, Lesourd and Morard (2000, p.8) mentioned that the main function of the LME is hedging which representing 75%-85% of turnover. Frequently used methods in copper trade by hedgers is a fixation method that includes three stage: fixation on one LME day settlement, fixation on the LME average and fixation on a spot price of the LME.

The next biggest copper trading markets are New York Merchantile Exchange (NYMEX) and Shanghai Futures Exchange (SHFE). SHFE was established in 1992 and it is a non-profit, self-regulating corporation. However, there is restriction for foreign participators and one should trade in SHFE through the local arbitrage. At this moment, EMC's 60% of all copper exports are linked to China, SHFE might play important role on hedging strategy but it can be more costly than trading LME due to market's specification.

## 2.3 Futures Contract Property and Hedging

In theory, futures contract is an agreement to buy or sell agreed amount of specified asset on a future fixed date at a price agreed beforehand and details of contracts are not negotiable. The futures contracts have its' standardized form and traded in exchanges. Main advantage of futures contract is extremely liquid contract that can be un-winded at any time by performing reverse trade thus it has number of arrangements to ensure participants safety. Clearing house helps to avoid default risk of client's broker by keeping track of all transactions that take place in the exchange and their operation is based on margin account. Operation of margin is as below:

- Initial margin: when the futures position is opened, each counter-party makes deposit at the clearing house's margin account.
- Maintenance margin: limited threshold that can not fall below on the margin account.
- Variation margin: an additional deposit of counter-party on his margin account to ensure that margin account will not fall below maintenance margin.
- Margin call: notice from clearing house to counter-party when maintenance margin fall below the agreed amount.

Each metal exchanges have different flexible margin rates. For example: Clearing house of LME is operated by Clearnet, initial margin rate vary across commodities and initial rate also changes time to time depending on volatility and maturity but no inter-dependence.

Considering hedging strategy, hedgers always wants to be protected against unfavorable price movement and to transfer at least most of risks to another party by using various hedging strategies. Producers of the commodity itself have a possibility to install insurance scheme by reversing position on futures market. More specifically, producers sell futures contract for their futures product and once contract approaches maturity, they can sell products on spot market and buy new futures contract. By this way, they can mirror gain (loss) from futures trading by loss (gain) from spot market. This is called zero-sum game. Christian (2004) checked whether future and spot markets are correlated. Author explains that risk of potential losses cannot be removed completely through futures market since these two markets are not completely correlated. However, he empirically proves that correlation coefficient for copper spot prices and 3-months futures prices was 0.989, spot prices and 27 months futures prices was 0.936 between 1999 and 2004. Futures insurance scheme do not require front-up installation costs such as option market beside transaction costs. If the hedger does not have financial strength to fund front-up costs, this is a possible market to hedge against unfavorable price movements. Success of a hedging strategy depends on market situation of spot and future prices. There are two types of market situation: Contango and Backwardation. Contango is a situation which future price is above the spot price on contract signed date and they converge as maturity date approaches. Backwardation is vice-versa and pricing of futures contract is more difficult in this situation. Christian (2004) states that until the beginning of 2004, world copper market was in contango situation and since then it moved to backwardation situation as a lack of supply. According to Brook Hunt(2014), world copper market had excess supply of copper during year 2012-2014 and the situation is expected to continue until the year 2017 due to exploitation of new copper resources (Table 2.2). From this prognosis, it can be concluded that market will be in situation of contango until the year 2017.

Table 2.2: World copper supply and demand forecasting until year 2019

| Index | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|
| Copper Supply | 20141 | 20756 | 22323 | 23419 | 24129 | 24428 | 24900 | 25243 |
| Copper Demand | 19589 | 20666 | 21938 | 22711 | 23572 | 24319 | 25008 | 25654 |
| Market Equilibrium | 553 | 90 | 385 | 709 | 557 | 110 | -108 | -412 |
| Copper Sources | 3855 | 3945 | 4330 | 5039 | 5596 | 5706 | 5598 | 5186 |

*Source:* Brook Hunt long-term analysis, 2014.

# Chapter 3

# Literature Review

The focus of the thesis is to investigate the hedge effectiveness among copper futures market in LME. Consequently, literature review will be concentrated on different studies analyzing commodity futures market and its effectiveness. In this context, numerous literatures make use co-integration and VAR to measure hedge effectiveness in copper futures market. In addition to conventional econometric methods, GARCH model is also extensively used as a powerful tool to quantify hedge effectiveness. This chapter has two main sections including concentrated on Efficient Market Hypothesis, Optimum Hedge Ratio and it's effectiveness. Below we will address the most important key factors on this thesis and then summarize it.

## 3.1 Efficient Market Hypothesis

### 3.1.1 Theoretical Background of EMH

Market efficiency independently developed by Eugene F. Fama and Paul A.Samuelson in mid 1960s from two different approaches (EMH and Random Walk Hypothesis). Both studies came with same conclusion and suggest if the market is efficient, prices will be unpredictable and there will be no arbitrage opportunities. The efficient market is a confidential zone for market participants without seeking any additional information related to the market, thus it must be properly analyzed before trading on market. First, Samuelson (1965) uses temporal pricing models of storable harvesting commodities and he proved that when price properly reflects all available information, it fluctuates randomly. However, Pesaran (2005) mentions that considering existence of risk averse traders in efficient market, Samuelson's contribution is only a statistical statement rather than coherent theory of asset pricing.

Studies of Fama (1965a;b; 1970) became very influential force for testing asset pricing models by contributing numerous econometric tests and providing a host of empirical regularities in financial market. Fama (1970) distinguishes three major versions of EMH:

- Weak or narrow efficiency: Current prices contain all publicly available information from historical price series
- Semi-strong efficiency: New public information immediately cause asset prices to change.
- Strong efficiency: Even inside information cannot bring arbitrage opportunity

Fama (1991) tests EMH jointly with underlying asset pricing models and to test the hypothesis, he indicated futures price as an unbiased estimator of future spot prices and Beck (1994) specifies cointegrating equation as:

$$S_t = \alpha + \beta F_{t-n} + u_t \tag{3.1}$$

where $F_{t-n}$ is the future price of a n period maturity contract, $S_t$ is the spot price at the maturity of the contract and $u_t$ is a white noise error process. If the market is efficient, spot price will reflect all available information from past futures prices and unbiasedness hypothesis requires:

$$\alpha = 0; \quad \beta = 1 \quad \text{and} \quad u_t \text{ are serially uncorrelated}$$

Rejection of these restrictions simply proves that market is inefficient or there is a risk premium in futures market.

### 3.1.2 Related Studies of EMH in Copper Futures Market

Numerous literatures cover various procedures for analyzing market efficiency of coppers futures market. Encompassing data of period between 1966 to 1984 from LME, Goss (1981) analyzes EMH by examining the unbiasedness of futures prices and spot prices for commodities of copper, tin, lead and zinc. Unbiasedness is rejected for copper and zinc, contrary result is shown for lead and tin. However, MacDonald & Taylor (1988a;b) research comes with evidence that for period 1976-1987, copper futures market is considered as efficient. Same database for copper futures market used by Fama & French (1987) and they have same conclusion as Goss (1981). More accurate evidence is given that both systematic risk premiums and forecasting power are contained. Canarella & Pollard (1986) uses both overlapping and non-overlapping data for four metals including copper, lead, tin and zinc futures contracts for the period 1975-1983 and EMH is not supported. Moreover, Chowdhury (1991) and Beck (1994) provide same result as previous author. Kenourgios & Samitas (2004) test cointegration of the copper spot and futures price series on a sample comprising the period between 1989 to 2000 of LME. The evidence of market efficiency is not found for the spot price and fifteen months futures prices. This anomaly disappears on a sample series of the spot price and three months futures prices. However, considering long-term and short-term efficiency, there was no satisfactory empirical result on cointegration. Overall, study suggests that copper futures market on the LME is inefficient. Otto (2011) employs ARMA approach to investigate speculative efficiency of six base metals (aluminium, copper, nickel, lead, tin and zinc) traded at the LME and sample database consists three months, fifteen months futures and spot prices for the period between 1991 to 2008. Two of findings are worth highlighting. Speculative efficiency hypothesis is rejected for all metals except for aluminum and 3-month lead contracts. As regards the effects of period, speculative efficiency reduced significantly after 2000. His finding is consistent with Kenourgios & Samitas (2004)'s even after including the period after 2000.

Three major versions of efficiency are suggested by Fama (1970) and Gross (1988) use semi-strong efficiency test for copper and aluminium futures markets. Database consists period from January 1983 to September 1984 and he used short-term futures contracts. By employing the criterion "mean square error", he summarized that both commodities futures market are efficient. For the weak-form efficiency test, Bird (1985) employs filtered techniques. For the period 1972-1982, LME is an inefficient market for copper, lead and zinc and tin futures market does not reject EMH.

If we look into the researches of copper forwards market of LME, Moore & Cullen (1995) analyze EMH for six base metals covering one and two months commodity and foreign exchange forward prices from period 1985-1989 and unbiasedness couldn't be rejected. Kavussanos *et al.* (2004) research is based on cointegration test by covering period 1996-2000 and evidence is in line with study of Moore & Cullen (1995) . However, Krehbiel & Adkins (1993) study rejects unbiasedness hypothesis for copper forwards market. Overall, empirical evidences show heterogeneous results regarding coppers futures market for both copper futures and forwards market. Thus to reject or not to reject unbiasedness or cointegration depends on test setups, contracts specificity considering maturity, type of contract, time-period and market.

Above studies are concentrated on single-market and single-contract framework. Sinha & Mathur (2013) study linkages of base metal futures traded in Indian Commodity Exchange and LME for period 2006-2013 by employing cointegration test and ARMA-GARCH approach. They were able to find trace of long-run cointegration between these two exchanges for five pairs of metals (aluminium, copper, nickel, lead and zinc). For coppers futures market, Indian Commodity Exchanges price runs in one direction to LME but not in the opposite direction. It is possible to analyze that if the copper futures market of LME is found to be inefficient and Indian Commodity Exchanges follows LME's price then also Indian market can be inefficient as well. Zhang (2003) investigates linkage between SHFE and LME for copper and aluminium futures trade and he finds a certain degree of integration between two exchanges[1]. LME covers almost 95% of the total world trade in copper futures contracts. So SHFE is likely to follow price determined by LME that means market inefficiency may be in presence in SHFE.

## 3.2 Hedging in Copper Futures Market

### 3.2.1 Theoretical background of Hedging

Hedging strategy is originated for market participant who wants to be protected against market uncertainty and to reduce the risk associated with price movement. Thus traders are of interest in valuing OHR and HE before making hedging decisions. Various types of OHR and hedger's objective functions are introduced in the theoretical literature. However, not all of them can be applied in empirical work as result of difficulty of employing certain mathematical and testable formulas to the computation. Based on hedger's perspective, OHR can be computed differently. Widely used approaches to compute OHR are as follow:

[1] Study of Zhang, G.P. (2003) is written in Chinese and this literature review is taken from study of D.Lien & Yang (2006)

- Naïve approach: For each spot position, one opposite position in the futures market is taken and the hedge ratio is always equal to 1. If two prices move by same amount to same direction, this approach is perfect and the simplest one.

- OLS approach: Hedge ratio is determined by the holding certain amount of futures contract against one share of the underlying asset.

$$\triangle S_t = \alpha + \beta \triangle F_t + u_t \tag{3.2}$$

  where $\triangle S_t$ and $\triangle F_t$ are the changes of logged spot prices and changes of logged futures prices, $u_t$ is identically, independently distributed error term and $\beta$ is the hedge ratio. This approach has a number of limitations. First of all, it ignores the covariance between error of spot and futures prices. Secondly, endogeneity of futures prices is not considered.

- Minimum Variance (MV): Based on minimization of the variance of the hedged portfolio and it is one of the widely used hedging strategy . This approach is suitable for risk averse traders and the hedge ratio remains optimal in both efficient and inefficient market. Disadvantages of such approach are that ignorance of expected return of the hedged portfolio and equal weight is given to negative and positive returns. Trader's portfolio function is formulated as:

$$R_{Pt} = R_{St} - h_t R_{Ft} \tag{3.3}$$

  where $R_{Pt}$ is portfolio return, $R_{St}$ is spot return, $h_t$ is hedge ratio and $R_{Ft}$ is futures return. Baillie & Myers (1991) developed that OHR can be computed based on information captured from time t-1 ($I_{t-1}$):

$$h_t | I_{t-1} = \frac{\mathrm{cov}(R_{St}, R_{Ft} | I_{t-1})}{\mathrm{var}(R_{Ft} | I_{t-1})} \tag{3.4}$$

- Minimization of Semi-Variance Approach: This one is similar to MV approach and only difference is that differentiated weight is given to negative and positive returns[2].

- Expected Utility Maximization Approach: Traders preference between the risk and return trade-offs is taken into account to compute OHR by

[2] Traders tend to avoid downside risk while keeping the upside potential.

maximizing the trader's utility. For computation, additional risk aversion coefficient is included. Kroner & Sultan (1993) first formulated this approach and utility maximization function is:

$$E_t U(R_{Pt}|I_{t-1}) = E_t(R_{Pt}|I_{t-1}) - \gamma \text{var}(R_{Pt}|I_{t-1}) \tag{3.5}$$

where $R_{Pt} = R_{St} - h_{t-1}R_{Ft}$ and $\gamma$ is the risk aversion coefficient. And OHR is computed as follow:

$$h_{t-1}|I_{t-1} = \frac{\text{cov}(R_{St}, R_{Ft}|I_{t-1})}{\text{var}(R_{Ft}|I_{t-1})} - \frac{1}{2\gamma}\frac{E(R_{Ft}|I_{t-1})}{\text{var}(R_{Ft}|I_{t-1})} \tag{3.6}$$

Performance of OHR between the models can be compared by computing hedging effective index HE. Ederington (1979) first measured HE as the percentage reduction in the variance of hedged portfolio against unhedged position and it is measured as:

$$HE = \frac{\text{var}(U) - \text{var}(H)}{\text{var}(U)} = \frac{\text{var}(R_{St}) - \text{var}(R_{St} - h_{t-1}R_{Ft})}{\text{var}(R_{St})} \tag{3.7}$$

where var$(U)$ is variance of spot return $R_{St}$ and var$(H)$ is variance of portfolio return $R_{Pt} = R_{St} - h_{t-1}R_{Ft}$. As HE evaluates the validity of the risk-return adjustment of the hedged portfolio, better the OHR, HE result will be closer to one.

### 3.2.2 Related Studies of HE in Copper Futures Market

There is a significant amount of empirical research that developed many different models on the computation of the OHR and it's effectiveness. The most-widely used approach to estimate OHR is to minimize variance of hedged portfolio. Jonhson (1960) was the first to introduce in the literature the MV approach for calculation of the number of futures contracts for an underlying asset on spot market since the spot and futures prices do not always move together. Ederington (1979) formulated HE index as a reduction of risk based on OHR computed by MV and established the first empirical model. The model is based on trade-off between risk and return from hedged portfolio and spot trading. He argues against naive approach that even pure risk minimizer will take less positions in futures market than spot markets. However, he makes strong assumption of homoscedasticity that ignores time-varying proportions on change in futures price and change in spot price. He concludes that MV hedge ratio is the OHR and HE declines with more distant contract. Benninga *et al.* (1984) use OLS approach to derive the OHR but there are strict assumption on unconditional distribution and time-invarient relationship between spot and futures prices. Ederington (1979) states that MV will be simultaneously reached while a hedger maximizes profit. But Benninga *et al.* (1984) argues that the minimization of income variance is equivalent to OHR. Later, more sophisticated models are introduced that allow time-varying hedging methods.

Engle (1982) is the first to report that OHR is time-varying if the changes in futures and spot prices are not time-invariant and he presented the volatility model ARCH. Also Pindyck (1984), Poterba & Summers (1986), Myers & Thompson (1989) and Baillie & Myers (1991) mention about necessity of consideration of time-varying variance[3]. It means OHR should be computed by variance of portfolio and covariance matrix of spot and futures prices. In late 1980, many models are developed that allow time-varying variance such as GARCH model and Dynamic Conditional Correlation (DCC) by Bollerslev (1986), Integrated-GARCH model similar to Exponentially Weighted Moving Average (EWMA) by Engle & Bollerslev (1986), ARCH-in mean by Engle & Granger (1987). In 1995, Engle & Kroner (1995) proposed multivariate GARCH (BEKK) model and the last recent approach is the cointegration test.

Kroner & Sultan (1993) find that time-varying hedging method out-performs constant hedge ratio and argues if the martingale pricing and joint normality assumptions are present, time-varying hedge ratios are identical to constant hedge ratio[4]. Study of Lee *et al.* (2006) supports the implication of Kroner & Sultan (1993). D.Lien & Luo (1993) used Error-Correction Model (ECM) to investigate the problem of over-hedging. By relaxing assumption of homoscedasticity over spot and futures prices, study concludes that OHR converges to the naïve hedge ratio over long-time horizon which is contrary to implication of Ederington (1979). However, Dewally & Marriott (2008) study emphasize that OHR does not converge to naïve ratio over time for copper market and suggest that the best hedging strategy is to hedge with time-varying OHR through contracts with maturity about 6 to 8 weeks.

Chen *et al.* (2004) demonstrate that longer the length of hedge horizons, greater the OHR and HE for both domestic and international hedging. How-

[3]S.Boutouria and Fathi Abid: Hedging Effectiveness of Constant and Time Varying Hedge Ratio of the Copper in the London Metal Exchange, 2010

[4]The martingale property implies that past events never helps predict the future outcome

ever later study of Chen *et al.* (2008) leads to contrary results by many other authors. By relaxing the assumption of joint densities for futures contracts, he examines 25 futures contract and reports that none of short-term contracts have joint normal distribution and normal distribution is found for a very few for longer-term contracts. Xiaoquan *et al.* (2010) employed Gumbel survival time-varying copula function to eliminate the restriction of joint normal distribution in analyzing the soybeans and copper futures contracts traded in Chinese commodity market[5]. One of the main findings is that in the copper market, hedging becomes less effective as the more the maturity increases. Boutouria & Abid (2010) also studied HE of copper contracts of the LME and they state that variance reduction for portfolio is greater for the 3 months contract. Their finding supports Xiaoquan *et al.* (2010) and Dewally & Marriott (2008).

As mentioned in previous section, traders are more sensitive to downside risk. Figlewski (1984) first studied the hedging performance based on basis risk. However, his study has a strong assumption of homoscedasticity. Pirrong & Ng (1995) summarize stylized facts about impact of size of basis for price volatility of energy futures market. They find that larger the basis size, more divergence of spot and futures prices and more volatile markets. Switzer & El-Khoury (2007) emphasizes that hedging performance can be improved by estimating price volatility with consideration of asymmetric impact of positive and negative basis. D.Lien & Yang (2006) compared HE indices with and without basis impacts by employing constant hedge ratio, OLS method and Dynamic Conditional Correlation (DCC) models in copper and aluminium futures contracts traded in SHFE by covering the period 1996-2004. They note that symmetric and asymmetric Bivariate Error Correction (BEC) models are used with DCC error correction for distinguishing negative and positive basis impacts. Allover, in their study, the asymmetric BEC-DCC model out performs other two models which implicates that basis has asymmetric effects on price volatility, thus it's impact must be accounted in hedging strategy. Also Xiaoquan *et al.* (2010) used OLS method, DCC models and copula functions for HE indices comparison. Among them, optimal copula function performed the best and DCC model provided the lowest HE for contracts with short maturity and OLS model for the contracts with 5-month maturity. Study concludes that spot and futures prices are more volatile during market downturn than upturn in the soybean market but almost symmetric in the copper market.

[5]The Gumbel copula (Gumbel, 1960) is an extreme asymmetric Archimedian copula value that exhibits greater dependence in the upper tail than in the lower tail.

Copula functions also employed for examining the OHR in financial futures by Hsu *et al.* (2008) and Cherubini *et al.* (2004) and it out-performs GARCH and DCC models.

By allowing heteroscedasticity, a large body of studies compared OHR and HE through many different econometric models. Regarding to Greek stock and futures market, Floros & Vougas (2004) computed hedge ratios covering period 1999-2001 and found that Bivariate GARCH model provided the better result than ECM, VECM and OLS. Superiority of ECM method is supported by Lim (1996) in a study of Nikkei 225 futures contracts. OLS hedge ratio performed the best result in study of Bystrom (2003) in electricity futures contracts of Norway and D.Lien *et al.* (2002) in currency, commodity futures and stock index returns. de Salles (2013) studies crude oil market and BGARCH model with VECH diagonal and the vector autoregressive model provided the best results. GARCH model is suggested by study of Rossi & Zucca (2002) when trader is hedging in LIFFE[6]. Yang (2001) and Kumar *et al.* (2008) support Multivariate GARCH model for estimating OHR in Australian and Indian futures market. In copper futures market, many extended GARCH models are applied. Number of findings must be highlighted here. Hall (1991) and Bracker & Smith (1999) find that GARCH model brings better estimation in LME and COMEX[7]. Boutouria & Abid (2010) employed various hedging models for copper futures contracts of the LME. In their study, GARCH model out-performs the OLS, VAR and MGARCH. Also time-varying hedge ratio derived from VAR-MGARCH and it gives the best OHR.

As a result of rapid global expansion of the international hedging number of studies address international portfolio context. International hedgers face price risk with additional risks of exchange rate volatility and transaction cost. In the report of Congressional Research Service for Congress, Jickling (2006) states that derivative markets demand relatively small transaction cost between 0.01% and 0.003%. Chou (1988) and Kroner & Sultan (1993) note that uncorrelation of exchange rate and futures asset price leads to identical OHR as of domestic hedgers. However, if the nation's economy is heavily dependent on commodity export, exchange rate is most likely to fluctuate resulting from the commodity markets volatility. Lui & Jacobsen (2011) empirically analyzed the possibility of hedging both asset and currency risks in one operation for the commodity and stack markets of U.S., the U.K., and Japan. Taking into account exchange

[6] London International Financial Futures and Options Exchange
[7] New York Commodity Exchange

rate risk and transaction cost, empirical result shows that international OHR have better practicability than separately hedging in currency and commodity markets.

# Chapter 4

# Data and Methodology

## 4.1 Hypothesis Development

In this section development of research hypothesis are introduced based on findings from existing literature with the author's prediction about behavior of metal exchanges. As mentioned in previous chapter, commodity market is well-known for its dramatic price volatility that caused by many unpredictable facts and non-diversifiable homogeneous products. From the perspective of nations with heavily dependent on commodity export, hedging in such market may come costly but can be helpful tool to ensure stable economic growth. Literature survey showed many different points of view about hedging in commodity market. This survey leads to following hypothesis before making any other choice regarding to hedging strategies:

***Hypothesis 1:*** *The copper futures market in LME is efficient and unbiased estimator of futures spot prices which means if the market is efficient, spot price will reflect all available information from past futures prices.*

As mentioned in chapter 2, EMC trades own resources based on LME's spot price and downgraded spot price leads EMC to adjust manufacturing process grades for copper ore and ore rocks against potential loss faced by EMC. First of all, defining the market efficiency is necessary step to investigate whether EMC's potential loss is avoidable completely or by a little grade. As Fama (1970) suggests when the market is efficient, spot price can be properly analyzed before trading on market. If it is the case, must manufacturing process management be applied by EMC? Thus Hypothesis 1 gives very important message to EMC.

If the first hypothesis is rejected and proves that there is a risk premium in futures market, it is important to introduce hedging strategy against unfavorable price movements and that leads to following analysis:

***OHR analysis:*** *Comparison of hedge effectiveness ratios from three different models based on characteristics of risk premium.*

To derive second hypothesis, market inefficiency is a necessary condition to be fulfilled. If the market is efficient, automatically hedge effectiveness ratio will be one. In this hypothesis, author predicts first hypothesis is to be rejected. Above two hypothesis are able to give accurate answer for the main question of the study "To hedge or Not to".

## 4.2 Data Description

To reach the objective of this work, author uses daily official settlement copper prices of LME in the spot and 3 month futures, quoted in US $ per tonne. The data is obtained from the LME and includes observations from the first trading day in 2000 till the 17th of September 2014.

LME employs computer auction trading and traditional open outcry auction systems. Trading hours (Ring) are 12:00-12:05, 12:30-12:35, 13:15-14:45, 15:10-15:15, 15:50-15:55, and 16:15-16:55 in local time. The computer auction system of the LME runs from 1:00-19:00 in local time. LME offers three different prices: official, unofficial and closing prices. Official settlement price is announced during the break between second and third ring and it is used as the global reference for physical contracts.

The spot and 3 months futures prices constructed as mentioned in the paragraphs are provided in the Figure 4.1,4.2 and 4.3. As shown in time series plots, both series' volatility is almost same as each other and major economic shocks can be seen between year 2005 and 2010.

Figure 4.1: The time series plot for SPOT prices

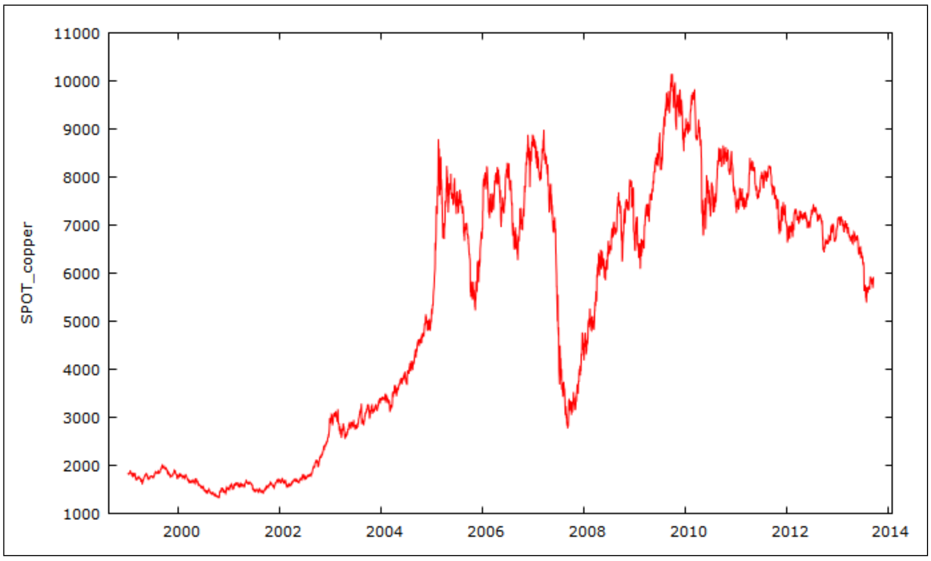



Figure 4.2: The time series plot for 3 MONTHS prices

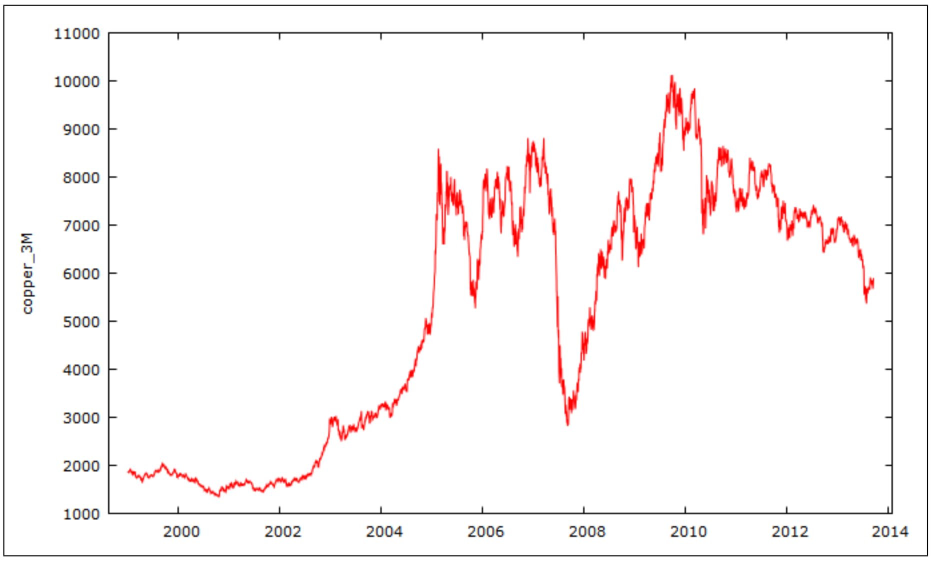


Figure 4.3: The association between spot and futures price.

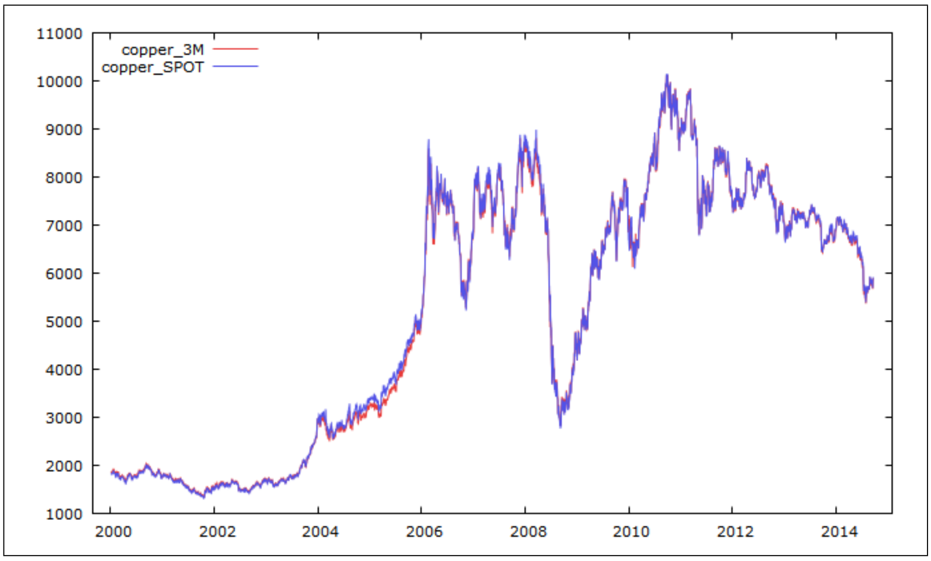



Table 4.1 also provides the basic descriptive statistics of spot and futures price as well as log of two prices. The table shows that the spot prices have a higher mean, higher standard deviation as well as higher coefficient of variation compared to futures prices. For both prices, median is higher than the mean.

Table 4.1: Summary statistics of used variables

| | **S_t** | **F_t** | **r_S_t** | **r_F_t** |
|---|---|---|---|---|
| **Mean** | 5194.7 | 5174.3 | 0.030563 | 0.029974 |
| **Median** | 6186.0 | 6175.0 | 0.023420 | 0.029670 |
| **Minimum** | 1319.0 | 1340.5 | -11.837 | -12.029 |
| **Maximum** | 10148. | 10124. | 11.349 | 11.507 |
| **Standard deviation** | 2677.4 | 2672.4 | 1.7152 | 1.6589 |
| **C.V.** | 0.51542 | 0.51647 | 56.120 | 55.342 |
| **Skewness** | -0.14910 | -0.13680 | -0.25895 | -0.23466 |
| **Ex. Kurtosis** | -1.5276 | -1.5460 | 3.7693 | 4.0366 |
| **5% percentile** | 1523.8 | 1542.9 | -2.6809 | -2.6736 |
| **95% percentile** | 8791.5 | 8775.5 | 2.7182 | 2.5791 |
| **Interquartile range** | 5483.3 | 5462.0 | 1.8406 | 1.7273 |
| **Missing observations** | 0 | 0 | 1 | 1 |

The log of spot and futures price are used for the analysis henceforth. To formally test the price series for stationarity Augmented Dickey-Fuller (ADF) by Dickey & Fuller (1981) unit root rests are employed. Since the null hypothesis of a unit root in the series is not rejected in the level by both tests, they are non-stationary. However in Table 4.2, they are stationary in the first difference thus original price series might be integrated of first order I(1)[1].

Table 4.2: Unit root tests

| ADF test - corresponding p-values | | | | |
|---|---|---|---|---|
| | levels | | differences | |
| variable | S_t | F_t | d_S_t | d_F_t |
| ADF cost | 0.5625 | 0.5097 | 0.0000 | 0.000 |
| ADF const. & trend | 0.8568 | 0.8643 | 0.0000 | 0.000 |

## 4.3 Econometric Models

For choosing the most suitable econometric models a plenty of researches regarding the hedge effectiveness in commodity market must be considered. This concerns the market efficiency and OHR. Following section will guide you to the econometric models such as OLS, Co-Integration test,ECM and GARCH.

### 4.3.1 Futures Market Efficiency

We have met with the standard statistical techniques of parameter restrictions of EMH as presented in Section 1.1 of Chapter 3. To estimate the equation (3.1) directly by OLS model, following problem must be overcame:

- Assumption of stationarity of two time series: When non-stationary is presence for both prices, OLS is an inadequate technique by violating the assumption of standard distributions and it leads to spurious regression unless both prices are cointegrated. In this situation, cointegration test or ECM can be introduced to test the EMH.

Let $F_{t-1}$ be the future price of a contract expiring at time $t$, $S_t$ is the spot price at the maturity of the contract. Risk neutral, efficient market implies that futures price $F_{t-1}$ is equal expected spot price $S_t$ based on given information at time $t-1$ and spot price will differ from the expected spot price in future only by an white noise amount $u_t$:

$$E_{t-1}(S_t \mid I_{t-1}) = F_{t-1} \tag{4.1}$$

[1]More details and other diagnostic tests are provided in Chapter 5

$$S_t = E_{t-1}(S_t \mid I_{t-1}) + u_t \tag{4.2}$$

where $E_{t-1}$ is the conditional expectation at time $t-1$, $I_{t-1}$ is the information gathered from time $t-1$ and $u_t$ is the white noise. This implications lead us to below equation and restrictions demonstrated by Fama (1991):

$$S_t = \alpha + \beta F_{t-1} + u_t$$

where $\alpha = 0$ ; $\beta = 1$ and $u_t$ are serially uncorrelated. Rejection of these restrictions simply proves that market is inefficient or there is a risk premium in futures market. But if the prices are non-stationary, Johansen Maximum Likelihood Procedure to test long run unbiasedness and ECM demonstrated by Engle & Granger (1987) to detect both short run and long run relationship jointly if variables cointegrated. Goodman & Schroeder (1991) introduced cointegration procedure to analyze long run market efficiency and implies that if prices are non-stationary, by using Johansen cointegration test white noise $u_t$ should be stationary in order to test EMH which is:

$$u_t = S_t - \alpha - \beta F_{t-1} \tag{4.3}$$

Under the parameter restrictions of $\alpha = 0$ and $\beta = 1$ Likelihood ratio (LR) tests are used to detect cointegration. If the cointegration still holds under the both restrictions, then the futures market is efficient and there is no time-varying risk premium. However, if the cointegration is found only under one restriction where $\beta = 1$ and $\alpha$ is non-zero, market is only efficient in long run with constant risk premium. But Ranganathan & Ananthakumar (2014) imply that this conclusion does not necessarily hold for short-run market efficiency and it can be tested by ECM applied by Engle & Granger (1987). Below equation is formulated for testing both long run and short run market unbiasedness:

$$\triangle S_t = \alpha + \beta \triangle F_t + \sum_{i=1}^{m} \lambda_i \triangle F_{t-i} + \sum_{j=1}^{n} \theta_j \triangle S_{t-j} + \rho \hat{u}_{t-1} + e_t \tag{4.4}$$

where $\triangle$ is the differentiation, $\hat{u}_{t-1}$ is the estimated error correction term derived from equation (4.3) that indicates the deviation from the long run equilibrium relationship, $e_t$ is a white noise and $S_{t-j}$ captures the short run dynamics. Efficient market parameter restrictions can be determined from the below expanded equation (4.4):

$$S_t - S_{t-1} = \alpha + \beta(F_{t-1} - F_{t-2}) + \sum_{i=1}^{m} \lambda_i \triangle F_{t-i} + \sum_{j=1}^{n} \theta_j \triangle S_{t-j} + \rho(S_{t-1} - \hat{\alpha} - \hat{\beta} F_{t-2}) + e_t \tag{4.5}$$

$$S_t = \alpha + (1+\rho) S_{t-1} - \hat{\alpha}\rho - (\beta + \hat{\beta}\rho) F_{t-2} + \beta F_{t-1} + \sum_{i=1}^{m} \lambda_i \triangle F_{t-i} + \sum_{j=1}^{n} \theta_j \triangle S_{t-j} + e_t \tag{4.6}$$

Efficient market hypothesis implies that the current spot price is derived only from the information given by the past futures prices thus coefficient of $S_{t-1}$ included in equation (4.6) must be insignificant under EMH term. Under constant risk premium presence, efficient market conditions (equation (4.7)) and unbiasedness condition (equation (4.8)) are as follows and can be tested separately:

$$1 + \rho = 0; \quad \beta + \hat{\beta}\rho = 0; \quad \beta \neq 0 \quad \text{and} \quad \lambda_i = \theta_j = 0 \tag{4.7}$$

$$\rho = -1; \beta = 1 \quad \text{and} \quad \lambda_i = \theta_j = 0. \tag{4.8}$$

Note: If cointegration is apparent with both restrictions of EMH, equations (4.7) and (4.8) are identical. Even all mentioned short run restrictions hold in each case, it does not simply imply that market is efficient allover due to non-zero $\alpha$.

### 4.3.2 Hedging Strategies in Futures Market

Hedging procedure involves mixture of short and long positions in a constructed portfolio to reduce to ensure the unfavorable price movement. Minimization of return variations of a certain asset can be realized through constructing the portfolio which is:

$$R_{P_t} = R_{S_t} - h_t R_{F_t} \tag{4.9}$$

where $R_{P_t}$ is the portfolio return at time $t$, $R_{S_t}$ is the spot return at time $t$, $R_{F_t}$ is the future return at time $t$ and $h_t$ is the hedge ratio. By computing variance of the hedged portfolio based on available information from time $t-1$ , OHR can be identified and it is as follow:

$$\mathrm{Var}(R_{P_t} \mid I_{t-1}) = \mathrm{Var}(R_{S_t} \mid I_{t-1}) - 2h\mathrm{Cov}(R_{S_t}, R_{F_t} \mid I_{t-1}) + h_t^2\mathrm{Var}(R_{F_t} \mid I_{t-1}) \tag{4.10}$$

where $\mathrm{Var}(R_{S_t} \mid I_{t-1})$ and $\mathrm{Var}(R_{F_t} \mid I_{t-1})$ are variance conditional and $\mathrm{Cov}(R_{S_t}, R_{F_t} \mid I_{t-1})$ is covariance conditional of the spot and futures prices. As mentions in Section 2.1 of Chapter 3, Baillie & Myers (1991) developed that OHR can be computed by Minimum-Variance approach that is:

$$h_t|I_{t-1} = \frac{\mathrm{Cov}(R_{St}, R_{Ft}|I_{t-1})}{\mathrm{Var}(R_{Ft}|I_{t-1})} \tag{4.11}$$

For choosing the best hedging strategy, Hedge effectiveness ratio (HE) is computed for each model and compares the performance of each model. Ku *et al.* (2007) suggest that index of HE can be expressed by:

$$HE = \frac{\mathrm{Var}_{unhedged} - \mathrm{Var}_{hedged}}{\mathrm{Var}_{unhedged}} \tag{4.12}$$

where $\mathrm{Var}_{hedged}$ indicates the variance of hedged portfolio and $\mathrm{Var}_{unhedged}$ is the variance of spot returns. Equation (4.13) implies that larger the risk reduction, higher the HE index. Hull (2002) also defined the HE index from slightly different aspect that is:

$$HE_{Hull} = h^2\frac{\mathrm{Var}(R_{Ft}|I_{t-1})}{\mathrm{Var}(R_{S_t} \mid I_{t-1})} \tag{4.13}$$

and larger risk reduction leads Hull's HE index closely to one.

Hedge ratio identifies the value of the proportion of a position that is hedged to the value of the entire position. Based on methodology of EMH, author considers following three OHR computation:

***1. OHR derived from OLS regression***: OHR is obtained by the regression:

$$\triangle S_t = \alpha + h_{\mathrm{OLS}}\triangle F_t + u_t \tag{4.14}$$

where $\triangle S_t$ and $\triangle F_t$ are the changes of logged spot prices and changes of logged futures prices, $u_t$ is identically and independently distributed disturbance term. Minimum variance hedge ratio is the coefficient $h_{\mathrm{OLS}}$ which is the slope of the OLS regression and regression R-squared can be used as a measure of hedging performance. However, this approach has a number of limitations such as ignorance of covariance between error of spot and futures return and endogenity of futures returns. If the endogenity is present, OLS is biased and inconsistent estimator.

***2. OHR with constant risk premium***: Many economic time-series are known to be non-stationary. However, if both series are unit roots and disturbance term from their regression is not a unit root, series are said to be cointegrated of order $d$ and disturbance term of order less than $d$. In this case, OHR can be computed by ECM. For the EMH we use ECM model with restrictions to test whether the market is efficient or not. However in this section, there are no restrictions are introduced.

$$\triangle S_t = \alpha + h_{\mathrm{ECM}} \triangle F_t + \sum_{i=1}^{m} \lambda_i \triangle F_{t-i} + \sum_{j=1}^{n} \theta_j \triangle S_{t-j} + \rho \hat{u}_{t-1} + e_t \tag{4.15}$$

where the $\hat{u}_{t-1} = S_{t-1} - \hat{\alpha} - \hat{\beta} F_{t-1}$ is the error correction term (ECT) which is the measurement of long-run equilibrium deviation and $h_{\mathrm{ECM}}$ is the OHR. To compute OHR from this model, unit root test should be run to find out stationarity of $\hat{u}_t$. The hedge performance is based on the lag length and minimization of the value of AIC and SBIC.

***3. OHR with time-varying risk premium - GARCH(p,q)***: Bell & Krasker (1986) argue that OHR itself being all time constant lies far from the reality. Because economic situation, hedging situation or historical event leads OHR to change overtime and they suggest GARCH model to estimate the OHR which captures unexpected information shocks to the market. GARCH (p,q) equation is as follow:

$$\sigma_t^2 = \alpha_0 + \sum_{i=1}^{p} \alpha_{t-i} \varepsilon_{t-i}^2 + \sum_{i=1}^{g} \beta_{t-i} \sigma_{t-i}^2 \tag{4.16}$$

where $\alpha_0$ is the mean, news of volatility from previous period $e_{t-1}^2$ is the ARCH effect, $\sigma_{t-1}^2$ is the GARCH term. In case of GARCH (1,1) and GARCH (2,1):

$$\sigma_t^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \beta_1 \sigma_{t-1}^2 \tag{4.17}$$

$$\sigma_t^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \alpha_2 \varepsilon_{t-2}^2 + \beta_1 \sigma_{t-1}^2 + \beta_2 \sigma_{t-2}^2 \tag{4.18}$$

where $h_{\mathrm{GARCH(1,1)}} = \beta_1$ is the OHR of GARCH(1,1) and $h_{\mathrm{GARCH(2,1)}} = \beta_1 + \beta_2$

is the OHR of GARCH(2,1). Kenourgios *et al.* (2008) defines three possibility of estimation results:

- $\sum_{i=1}^{p} \alpha_{t-i} + \sum_{i=1}^{g} \beta_{t-i} \approx 1$: persistence in volatility is high and there is a large positive shock $e_{t-1}$ that cause conditional variance $\sigma_{t-1}^2$ to be increased.
- $\sum_{i=1}^{p} \alpha_{t-i} + \sum_{i=1}^{g} \beta_{t-i} > 1$: Shock is permanently remembered in the estimation.
- $\sum_{i=1}^{p} \alpha_{t-i} + \sum_{i=1}^{g} \beta_{t-i} < 1$: Shock dies out overtime.

***4. OHR with time-varying risk premium - EGARCH(1,1)***

The EGARCH model implies that the leverage effect is exponential and market volatility reacts differently to negative or positive shocks. Model is given by the equation:

$$log\sigma_t^2 = \omega + \beta_{\text{EGARCH}} log(\sigma_{t-1}^2) + \gamma(\frac{e_{t-1}}{\sigma_{t-1}}) + \alpha|\frac{e_{t-1}}{t-1}| \tag{4.19}$$

where $\omega, \alpha, \beta$ and $\gamma$ are constant parameters and $\beta_{\text{EGARCH}}$ is the OHR. When the $\gamma$ is negative and significantly different than zero in the result, it implies that negative shocks creates greater volatility in the market.

***4. OHR with constant risk premium and conditional variance-ECM-GARCH(1,1)***

While GARCH (1,1) predicts conditional variances ECM model accounts error correction term with constant variances. Dlamini suggested the ECM-GARCH(1,1) which can capture conditional variances to the ECM and equations are as follows:

$$\triangle S_t = \alpha + h_{\text{ECM-GARCH}} \triangle F_{t-1} + \sum_{i=2}^{m} \lambda_i \triangle F_{t-i} + \sum_{j=1}^{n} \theta_j \triangle S_{t-j} + \rho \hat{u}_{t-1} + e_t \tag{4.20}$$

$$e_t | \Omega_{t-1} \sim N(0, \sigma_t^2) \tag{4.21}$$

$$\sigma_t^2 = \alpha_0 + \alpha_1 e_{t-1}^2 + \beta_1 \sigma_{t-1}^2 \tag{4.22}$$

where equation 4.19 and 4.20 capture the information given from the conditional variance $\sigma_t^2$ and equation 4.18 is ECM that includes residuals from the GARCH (1,1) and $h_{\text{ECM-GARCH}}$ is the OHR. ECM-GARCH(1,1) assumes that the conditional correlation between spot and futures prices is constant.

Dlamini concludes that this model corrects inefficiency of OLS hedge ratio and ECM limitation thus the result can be optimal risk minimization for a spot position.

Final note: Methodology used for EMH and computation for OHR are identical for the models OLS and ECM. Thus we will not run models twice for each hypothesis. If the market is efficient, above introduced restrictions will automatically hold during the computation of OHR.

# Chapter 5

# Empirical Analysis

## 5.1 OLS approach

We start the OHR analysis with the basic OLS approach that regresses the future returns on the spot returns. In Model 1, the resulting hedge ratio of 0.9626 is close to unity and may be challenged by more sophisticated modelling techniques.

**Model 1.1**: OLS, using observations 2000-01-04–2014-09-16 ($T = 3836$)
Dependent variable: r_S_t

| | Coefficient | Std. Error | $t$-ratio | p-value |
|---|---|---|---|---|
| const | 0.00171037 | 0.0101137 | 0.1691 | 0.8657 |
| r_F_t | 0.962565 | 0.00609661 | 157.8852 | 0.0000 |

In case of the time series analysis, OLS performance is limited by the OLS assumption. The literature review shows that the OLS can be finally superior to some advanced models but it depends on the particular circumstances. One of the major drawbacks of OLS estimation is that the distribution of spot and future returns changes with time and *usually* brings the phenomen of conditional heteroscedasticity. OLS constant hedge ratio is not able to capture this risk and may become strongly biased estimator and therefore expose the potential investor to larger and unexpected risk.

Table 5.1: Tests for the validity of CLRM assumption

| | test statistics | value | p-value | sign. |
|---|---|---|---|---|
| **Test for heteroscedasticity** | | | | |
| White | LM | 198.04 | 0.000 | *** |
| Breusch-Pagan | $TR^2$ | 38.051 | 0.000 | *** |
| **LM test for autocorrelation** | | | | |
| | LMF | 163.00 | 0.000 | *** |

Figure 5.1: The test for the normality of OLS errors

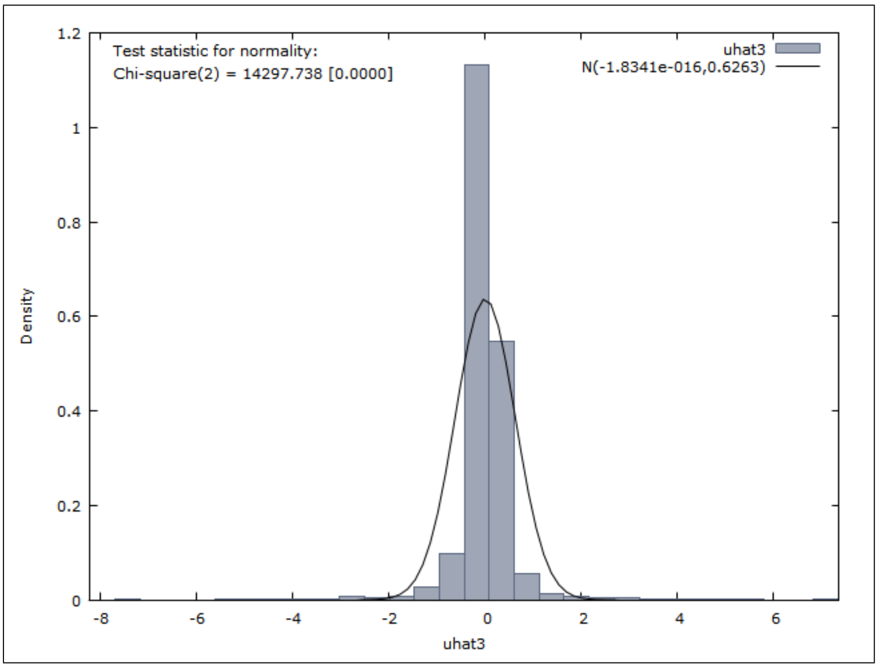



Figure 5.1 implies that residuals are not normally distributed and violates the normality assumption. The rejected hypothesis of normality of residuals does not cause major interpretation troubles for the OLS estimator. Table 5.1 shows the results of tests for the heteroscedasticity and autocorrelation assumptions of the OLS, both of classical assumptions are violated and requires using the heteroskedasticity-autocorrelation consistent (HAC) standard errors for the proper inference. This adjustment has been made in Model 1.2.

Model 1.2: OLS, using observations 2000-01-05–2014-09-17 ($T = 3836$)
Dependent variable: r_S_t
HAC standard errors, bandwidth 11 (Bartlett kernel)

| | Coefficient | Std. Error | $t$-ratio | p-value |
|---|---|---|---|---|
| const | 0.00171037 | 0.00458815 | 0.3728 | 0.7093 |
| r_F_t | 0.962565 | 0.0134260 | 71.6942 | 0.0000 |

| | | | |
|---|---|---|---|
| Mean dependent var | 0.030563 | S.D. dependent var | 1.715160 |
| Sum squared resid | 1503.876 | S.E. of regression | 0.626296 |
| $R^2$ | 0.866698 | Adjusted $R^2$ | 0.866663 |
| $F(1, 3834)$ | 5140.064 | P-value($F$) | 0.000000 |
| Log-likelihood | −3647.063 | Akaike criterion | 7298.125 |
| Schwarz criterion | 7310.630 | Hannan–Quinn | 7302.567 |
| $\hat{\rho}$ | −0.392452 | Durbin–Watson | 2.784900 |

In general, on the top of that the usage of OLS estimation is not appropriate because the data from its nature violates the standard cross-sectional properties of the data traded by OLS. In our case, the endogeneity is tested since it can make OLS to be biased and consistent. Therefore the resulting hedge ratio might not to be the proper one to use. The correlated errors containing part of variability of explanatory and explained variable would cause the same problem. In addition, using the non-stationary variables also underestimates standard errors and inflates the inference. Spurious regression from correlated errors and trending relationships can report misleading inference and coefficient significantly different from its true value.

Table 5.2: Hausmann-Wu test for endogenity

| **test statistics** | **value** | **p-value** | **sign.** |
|---|---|---|---|
| Chi-square(1) | 0.161888 | 0.687 | |

Looking at Table 5.2, in our data the endogeneity is not the main issue since the Hausmann-Wu test is not able to identify the presence of endogeneity[1]. However, the major problem is in the existence of ARCH effect (see the Table 5.3). Such findings report the existence of conditional heteroskedasticity and inappropriateness of OLS method which serves us as the benchmark for more advanced estimators.

[1]Even if the test is not primarily used from time series analysis

Table 5.3: Test for ARCH effects

| coefficient | std. | error | t-ratio | p-value |
|---|---|---|---|---|
| alpha(0) | 0.110738 | 0.0321422 | 3.445 | 0.0006 |
| alpha(1) | 0.321550 | 0.0161311 | 19.93 | 3.42e-084 |
| alpha(2) | -0.0296679 | 0.0167482 | -1.771 | 0.0766 |
| alpha(3) | 0.196964 | 0.0164496 | 11.97 | 1.84e-032 |
| alpha(4) | 0.160579 | 0.0167482 | 9.588 | 1.57e-021 |
| alpha(5) | 0.0684542 | 0.0161311 | 4.244 | 2.25e-05 |
| **test statistics** | **value** | **p-value** | **sign.** | **ARCH** |
| LM | 1108.75 | 1.69893e-237 | *** | presented |

## 5.2 Error Correction Model approach

As we find in previous section, the OLS technique is not fully appropriate for the estimation of hedge ratio since assumptions of CLRM are not fully met. Even if the presence of the endogeneity is not significant from the test, OLS modelling is not able to capture the time-varying conditional heteroscedasticity which is crucial for the proper optimization of hedging process. Hence, the constant ratio is supposed to be inefficient and the usage of advanced techniques is required.

In the following section the Error Correction Model (ECM) approach is suggested to improve the OLS estimates with taking into account the assumption that error correction term has a significant impact on the spot price development. Also this model allows us to work with the non-stationary time-series data.

### 5.2.1 Cointegration test

The cointegration regression and the Engle-Granger test results in Table 5.4 imply that both series are integrated of order I(1) because the stationarity is not rejected for the particular variables (see Table 4.2) and at the same time the unit-root hypothesis for the residuals (Figure 5.2) from the cointegration regression is strongly rejected.

**Model 2**: Cointegrating regression
using observations 2000-01-04–2014-09-17 ($T = 3837$)
Dependent variable: S_t

| | Coefficient | Std. Error | $t$-ratio | p-value |
|---|---|---|---|---|
| const | 12.5281 | 2.63084 | 4.7620 | 0.0000 |
| F_t | 1.00152 | 0.000451763 | 2216.9055 | 0.0000 |

| | | | |
|---|---|---|---|
| Mean dependent var | 5194.684 | S.D. dependent var | 2677.448 |
| Sum squared resid | 21441392 | S.E. of regression | 74.77283 |
| $R^2$ | 0.999220 | Adjusted $R^2$ | 0.999220 |
| $F(1, 3835)$ | 4914670 | P-value($F$) | 0.000000 |
| Log-likelihood | −21998.03 | Akaike criterion | 44000.06 |
| Schwarz criterion | 44012.56 | Hannan–Quinn | 44004.50 |
| $\hat{\rho}$ | 0.834521 | Durbin–Watson | 0.330838 |

Figure 5.2: Residual plot after the conintegration regression

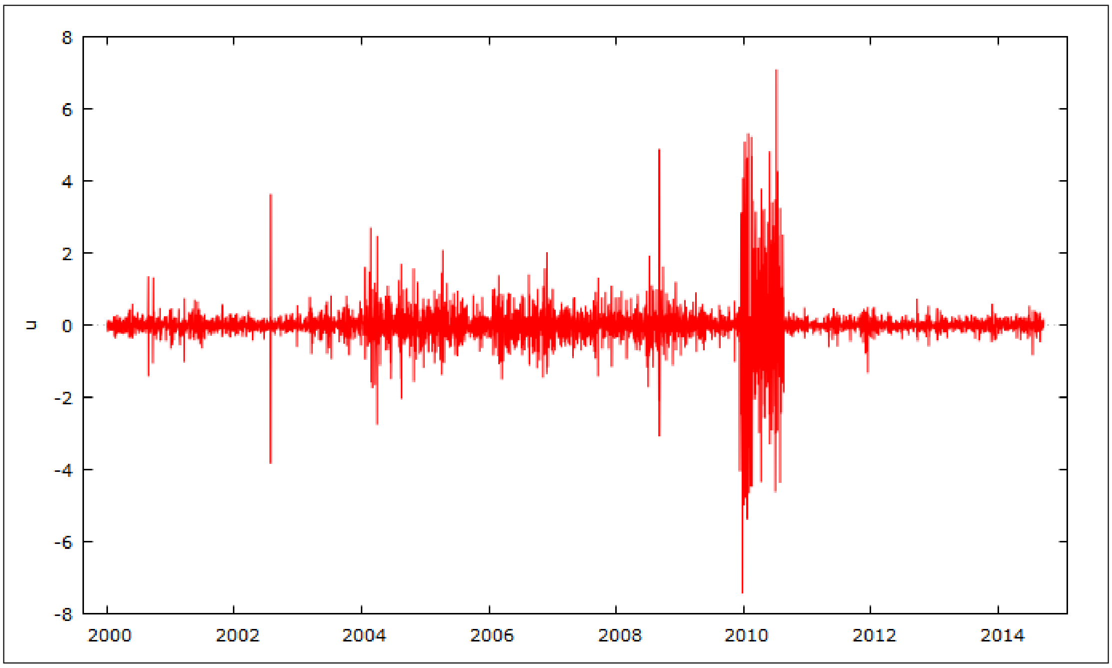



Table 5.4: Augmented Dickey-Fuller test for residuals

Engle-Granger Cointegration test

| unit-root null hypothesis: a = 1 | | | |
|---|---|---|---|
| test statistics | value | p-value | sign. |
| tau_c(2) | -9.35419 | 0.000 | **** |

Having the evidence of cointegration, there is a motivation to use the ECM method and try to estimate the improved hedge ratio with two step procedure including lagged error term and lagged spot and future price variables in order to capture the short-run dynamics.

We use Information Criterion (IC) comparison method to search the optimal length of variable lag, which is based on the minimizing IC values and checking the significance of chosen lagged variables. The lag that minimises the Akaike (AIC), Schwarz (SBIC) and Hannan-Quinn (HIC) criterions is equal to 2 (see Table 5.5).

Table 5.5: IC comparison - optimal lag length

| lag length | **Akaike IC** | **Hannan-Q. IC** | **Schwarz IC** | **sign. coef.** |
|---|---|---|---|---|
| (1,1) | 6655 | 6666 | 6686 | not |
| **(2,2)** | **6649** | **6664** | **6693** | **yes** |
| (3,3) | 6651 | 6671 | 6707 | not |
| (4,4) | 6650 | 6663 | 6707 | not |
| (5,5) | 6656 | 6668 | 6695 | not |

**Model 3**: ECM, optimal lag length (2,2)
using observations 2000-01-07–2014-09-17 ($T = 3834$)
Dependent variable: r_S_t

| | Coefficient | Std. Error | $t$-ratio | p-value |
|---|---|---|---|---|
| const | 0.00742344 | 0.0202774 | 0.3661 | 0.7143 |
| r_F_t | 0.976478 | 0.00563337 | 173.3382 | 0.0000 |
| F_t_1 | −0.000578476 | 0.000250992 | −2.3048 | 0.0212 |
| F_t_2 | 0.000577293 | 0.000251039 | 2.2996 | 0.0215 |
| u_1 | −0.434518 | 0.0229649 | −18.9210 | 0.0000 |
| r_S_t_1 | 0.0296890 | 0.0154856 | 1.9172 | 0.0553 |
| r_S_t_2 | −0.0105186 | 0.00548338 | −1.9183 | 0.0552 |

| | | | |
|---|---|---|---|
| Mean dependent var | 0.030607 | S.D. dependent var | 1.715517 |
| Sum squared resid | 1267.041 | S.E. of regression | 0.575395 |
| $R^2$ | 0.887679 | Adjusted $R^2$ | 0.887503 |
| $F(6, 3827)$ | 5040.822 | P-value($F$) | 0.000000 |
| Log-likelihood | −3317.661 | Akaike criterion | 6649.323 |
| Schwarz criterion | 6693.084 | Hannan–Quinn | 6664.869 |
| $\hat{\rho}$ | −0.007421 | Durbin's $h$ | −1.616057 |

In Model 3, the OHR estimated by OLS is significantly increased from 0.9625 to 0.9765, therefore the OLS estimate may be underestimated and as the model suggests the larger proportion of future contract may be required to reach the minimal portfolio variance.

In addition to this, the lagged error term coefficient is negative and significant, thus the effect goes against the difference between spot and future price to sustain the LR equilibrium which means positive difference induces negative spot price development in the next period. The adjusted $R^2$ is improved by 1.2% and standard error was decreased, therefore the ECM approach may be seen as step forward from the traditional OLS approach.

### 5.2.2 The Efficient Market Hypothesis

For testing the EMH, OLS technique is inadequate one because of non-stationarity of two series as shown in Table 4.2 however restrictions of $\alpha = 0$ and $\beta = 1$ hold in OLS regression (see Model 1). Since prices are non-stationary, Johansen cointegration test is used for further investigation. From the result of cointegration test shown in Model 2 , we can see that $\alpha = 12.528$ and $\beta = 1.002$. It indicates that copper market is efficient only in long-run with constant risk-premium.

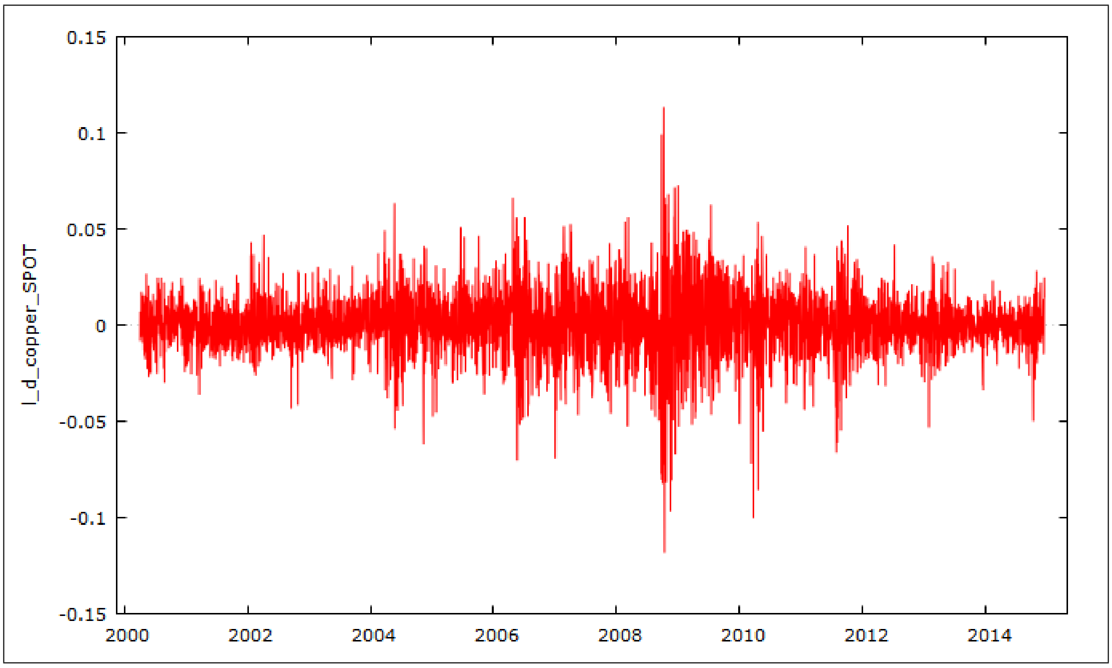
For the short-run market efficiency, market efficiency and market unbiasedness are tested seperately. Basically we can investigate presence of restrictions in equation (4.6) in Chapter 4 from the ECM results shown in Model 3. First of all,restriction of $1 + \rho = 0$ must be hold for both efficiency and unbiasedness conditions. Secondly, restriction of $\beta \neq 0$ for efficiency condition and $\beta = 1$ for unbiasedness condition must hold respectively. In Model 3, $\beta = 0.976$ indicates that market is biased and $1 + \rho = 0.0297$ indicates that market is biased and inefficient. All together, ECM model imply that market is inefficient in short-run.

From above all analysis, we can conclude that copper market is inefficient in LME with 3 months futures contracts.

## 5.3 GARCH approach

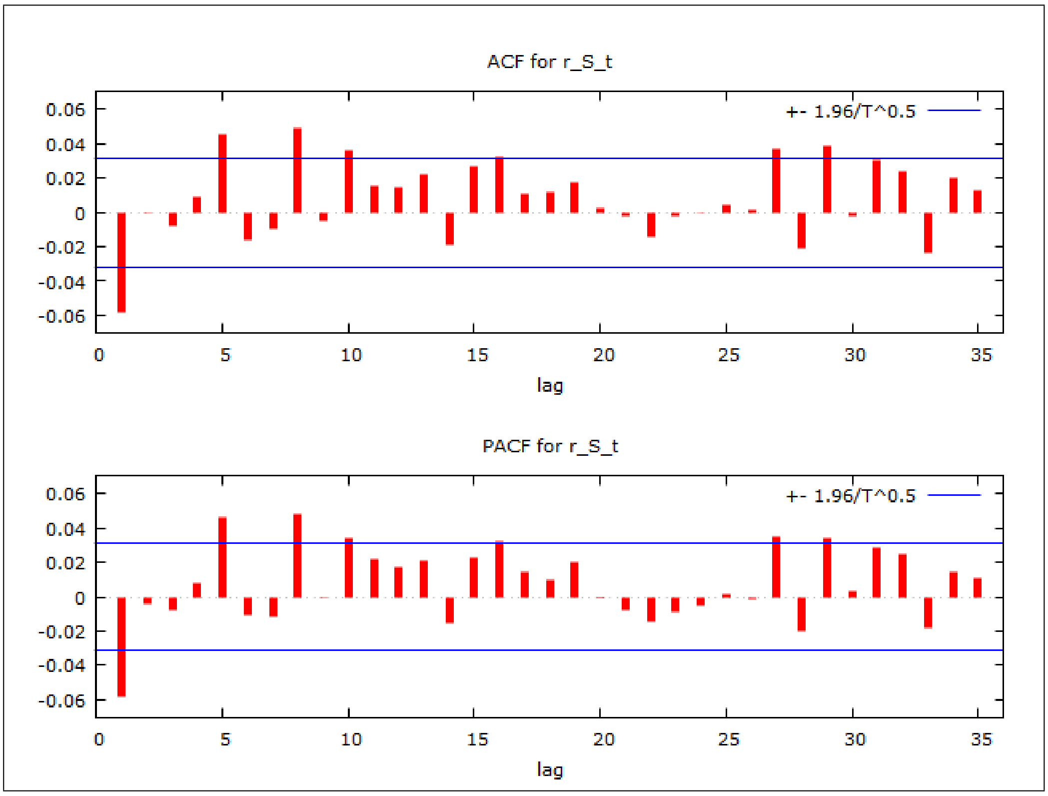
The standard time series analysis suggest using the log-difference transformation (as described above), hence the Table 4.2 presents the Augmented Dickey-Fuller test for corresponding time series. The results obviously shows the non-stationarity of the original series of 3 months and spot prices as well as the stationarity (see Figure 5.3) of transformed first differences (log-diff transformation with even lower p-values).

Figure 5.3: Time series plot of SPOT returns




We perform standard time series analysis to choose the best suitable ARIMA process and consequently analyse the residuals for potential ARCH effects. As shown in Figure 5.4, the correlogram, the ACF and PACF functions are not even close to any well known pattern, therefore we use the Box-Jenkins methodology to optimize the process parameters.

Figure 5.4: The correlogram for Copper SPOT returns



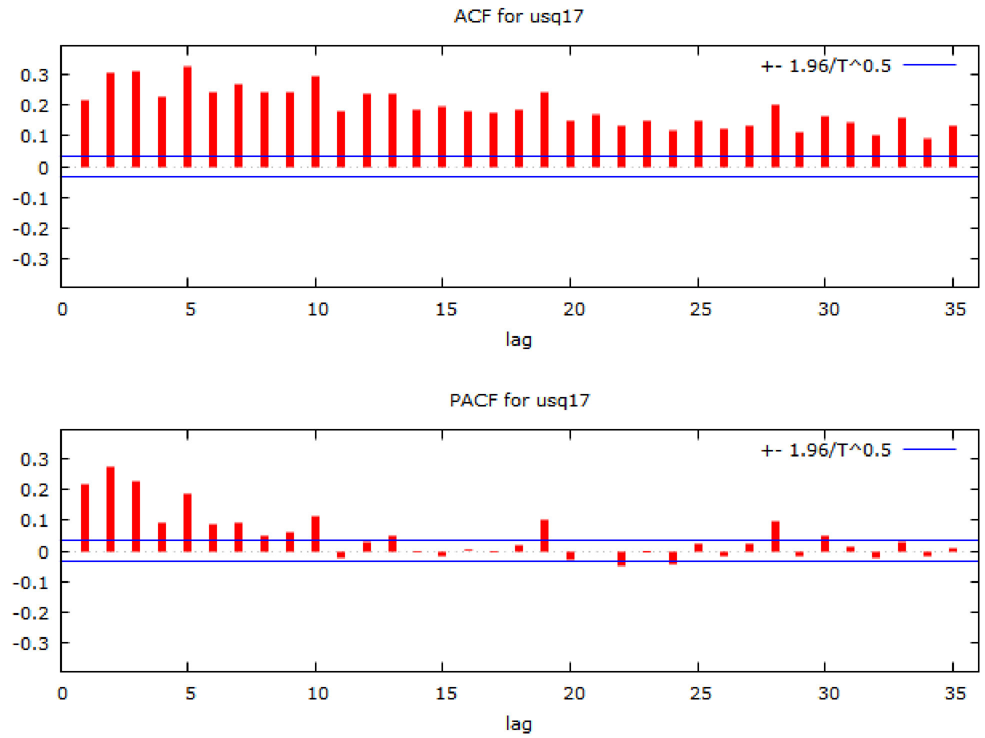

The procedure suggests to estimate the $p$ and $q$ and assess their appropriateness using the information criterions reported with the regression results: AIC, HIC and SBIC. The key driver is the value of the criterion - the lower the value, better the our model is. In addition, all the estimates (MA *&* AR roots) should be significant. From this point of view we identify the best ARMA and ARIMA model.

Table 5.6: The most appropriate ARMA model using Box-Jenkins

| | **p** | **q** |
|---|---|---|
| **Akaike Info Criterion:** | 5 | 7 |
| **Hannan-Quinn Criterion:** | 1 | 0 |
| **Schwarz Criterion:** | 1 | 0 |

Table 5.6 reports the suggested ARMA parameters. ARMA(1,0) seems to be slightly preferred it is indeed much more simple process than ARMA(5,7), two of three information criterion are lower for ARMA(1,0) therefore this model pattern was tested.

Figure 5.5: Residual plot after the cointegration regression




res.png

As shown in Figure 5.5, ACF and PACF after ARMA(1,0) still shows that there might be still linear dependent structures which could be the indicator of the fact that the variance is not constant over time. Consequently, the data were tested for the ARCH effect presence (i.e. $H_0 : \beta_1 = \ldots = \beta_q = 0$) against the alternative, for beta being ARCH($q$) estimate.

**Model 4**: ARMA, using observations 2000-04-05–2014-09-17 ($T = 3771$)
Dependent variable: r_S_t

| | Coefficient | Std. Error | $z$ | p-value |
|---|---|---|---|---|
| const | 0.0327180 | 0.0264631 | 1.2364 | 0.2163 |
| $\phi_1$ | −0.0583534 | 0.0162581 | −3.5892 | 0.0003 |

| | | | |
|---|---|---|---|
| Mean dependent var | 0.032731 | S.D. dependent var | 1.723027 |
| Mean of innovations | −8.56e–06 | S.D. of innovations | 1.719862 |
| Log-likelihood | −7395.621 | Akaike criterion | 14797.24 |
| Schwarz criterion | 14815.95 | Hannan–Quinn | 14803.89 |

| | | | Real | Imaginary | Modulus | Frequency |
|---|---|---|---|---|---|---|
| AR | | | | | | |
| | Root | 1 | −17.1370 | 0.0000 | 17.1370 | 0.5000 |

Test for ARCH of order 5 –
Null hypothesis: no ARCH effect is present
Test statistic: LM = 746.668
with p-value = $P(\chi^2(5) > 746.668) = 0.97557\text{e-}159$

Regarding the results in Model 4, LM = 746.668 with p-value = .97557e-159, the LM-ARCH test rejects the null hypothesis of no conditional heteroscedasticity of the residuals after ARMA $(1, 0)$. If we plot the squared residuals (Figure 5.5) one may see the PACF decaying relatively slowly and after the lag 10, ACF decaying very very slowly, which means that there really exists a serial dependence in the data variances.

Ljung-Box (test statistics: 36.69 with p-value=0.0005) and Portmentau statistics (test statistics: 36.57 with p-value=0.0003) are strongly reject the null hypothesis of no autocorrelation in model residuals, hence, there is a strong evidence for presence of the conditional heteroscedasticity and supports using Generalized Autoregressive Conditional Heteroscedasticity model (GARCH) (see Appendix A).

### 5.3.1 GARCH family models

GARCH estimation with two term specifications (1,1) and (2,1) are presented in Models 5 and 6. All the terms are significant and only the $\beta_2$ coefficient in GARCH (2,1) is on the edge, therefore it seems that the past shocks have still the impact on the future volatility of returns.

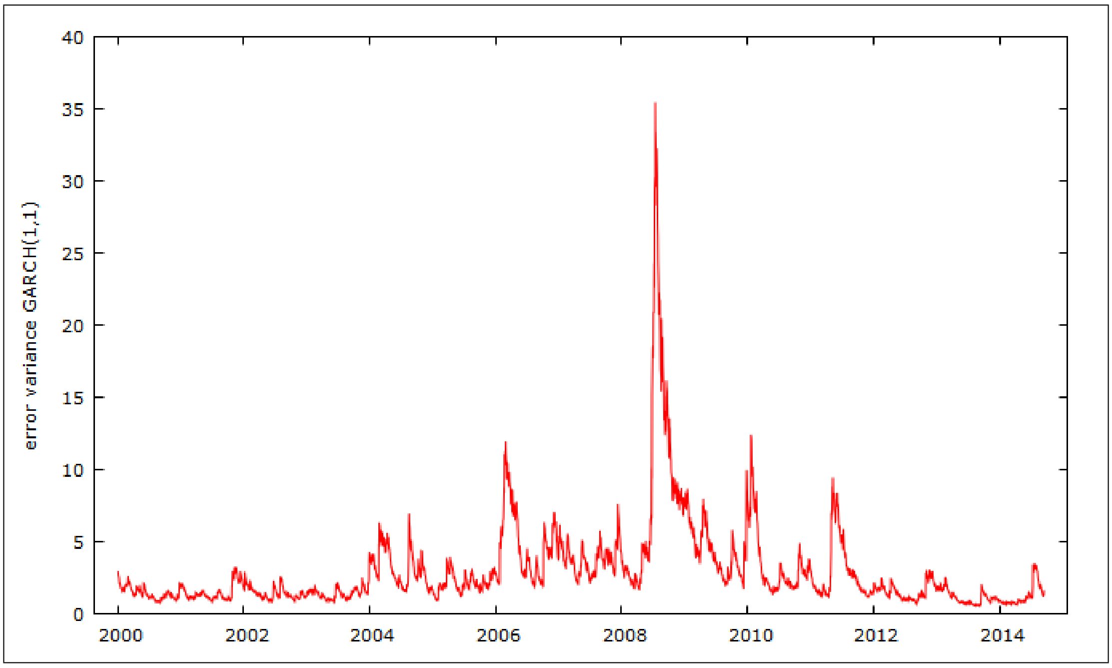
**Model 5**: GARCH (1,1) using observations 2000-01-04–2014-09-16 ($T =$ 3836)
Dependent variable: r_S_t
Standard errors based on Hessian

| | Coefficient | Std. Error | $z$ | p-value |
|---|---|---|---|---|
| const | 0.0276486 | 0.0212113 | 1.3035 | 0.1924 |
| $\alpha_0$ | 0.0221509 | 0.00599041 | 3.6977 | 0.0002 |
| $\alpha_1$ | 0.0652370 | 0.00743479 | 8.7746 | 0.0000 |
| $\beta_1$ | 0.927481 | 0.00818703 | 113.2866 | 0.0000 |

| | | | |
|---|---|---|---|
| Mean dependent var | 0.030563 | S.D. dependent var | 1.715160 |
| Log-likelihood | −6959.156 | Akaike criterion | 13928.31 |
| Schwarz criterion | 13959.57 | Hannan–Quinn | 13939.42 |

Unconditional error variance = 3.04208

Figure 5.6: Plot of GARCH (1,1) estimated volatility




In Model 5, it seems like the impact is remembered since the $\alpha_1 + \beta_1 < 1$ but the effect diminishes with time (same situation for GARCH(2,1) model-Model 6). It is obvious that the heteroscedasticity was not completely removed since the LM-ARCH test still reject the hypothesis of no ARCH effect for both models (see Appendix A).

**Model 6**: GARCH(2,1) using observations 2000-01-04–2014-09-16 ($T = 3836$)

Dependent variable: r_S_t

Standard errors based on Hessian

| | Coefficient | Std. Error | $z$ | p-value |
|---|---|---|---|---|
| const | 0.0273940 | 0.0211698 | 1.2940 | 0.1957 |
| $\alpha_0$ | 0.0283069 | 0.00817638 | 3.4620 | 0.0005 |
| $\alpha_1$ | 0.0854588 | 0.0137680 | 6.2071 | 0.0000 |
| $\beta_1$ | 0.561446 | 0.190275 | 2.9507 | 0.0032 |
| $\beta_2$ | 0.343780 | 0.179147 | 1.9190 | 0.0550 |

| | | | |
|---|---|---|---|
| Mean dependent var | 0.030563 | S.D. dependent var | 1.715160 |
| Log-likelihood | −6957.657 | Akaike criterion | 13927.31 |
| Schwarz criterion | 13964.83 | Hannan–Quinn | 13940.64 |

Unconditional error variance = 3.0389

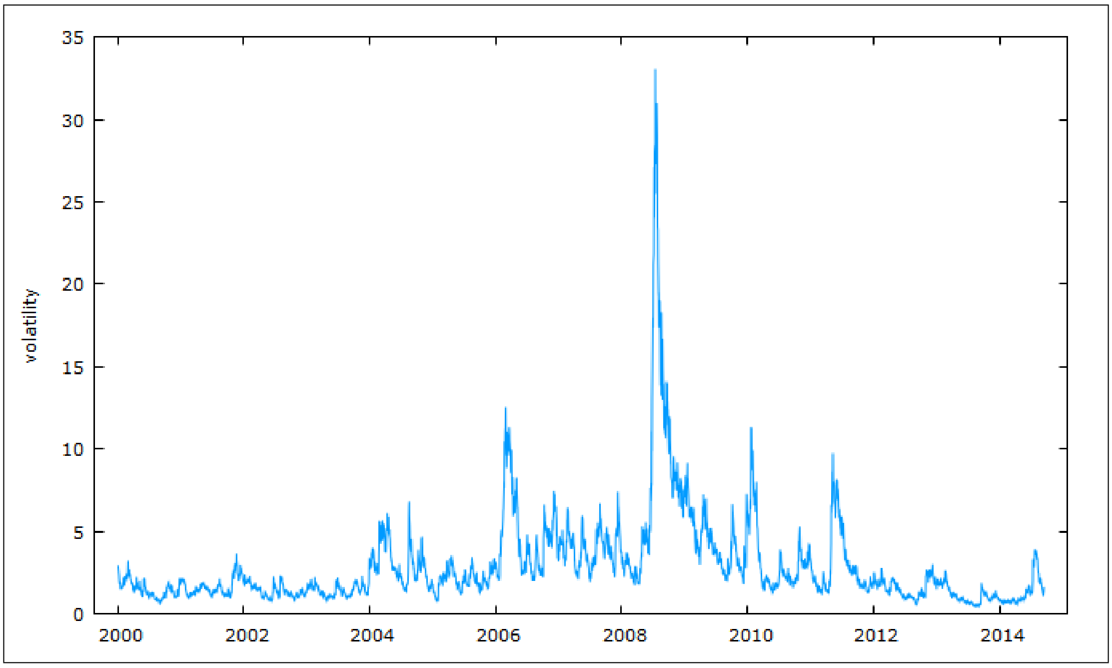
Regarding the results of GARCH models, EGARCH(1,1) method has been introduced to identify the character of reaction to shocks. In Model 7, the estimation results show that $\gamma$ coefficient is significant and negative, therefore the time series is slightly more sensitive to the negative news and they create more volatility than the positive shocks. Such findings seem to be in accordance with latest experience (see Figure 5.6) when the huge volatility in the data sample is connected with the financial crisis period. On the other hand, the LM-ARCH test reports again that the heteroscedasticity is not completely removed. Regarding the information criteria (higher almost two fold than OLS/ECM approach), it seems that neither the GARCH approach is fully efficient for the risk modelling and minimizing the portfolio variance. The EGARCH approach suggests the highest hedging ratio but 0.987 does not seems to be reasonable regarding the model statistics and ARCH test results.

**Model 7**: EGARCH(1,1) [Nelson] (Normal)
Dependent variable: r_S_t
Sample: 2000-01-04-2014-09-16 (T = 3836), VCV method: Robust

| | Coefficient | Std. Error | $z$ | p-value |
|---|---|---|---|---|
| const | 0.0138101 | 0.0146076 | 0.945 | 0.3445 |
| $\omega$ | -0.108210 | 0.0159161 | -6.799 | 0.0000 |
| $\alpha$ | 0.153250 | 0.0231045 | 6.633 | 0.0000 |
| $\gamma$ | -0.022031 | 0.0095748 | -2.301 | 0.0214 |
| $\beta$ | 0.986699 | 0.0041025 | 240.5 | 0.0000 |

| | | | |
|---|---|---|---|
| Log-likelihood | −6965.314 | Akaike criterion | 13940.63 |
| Schwarz criterion | 13971.89 | Hannan-Quinn | 13951.73 |

Figure 5.7: Plot of EGARCH estimated volatility




## 5.4 ECM-GARCH approach

The final model that we decided to consider is the ECM-GARCH approach. It combines two previous methods and uses the Error Correction Model which accounts for the GARCH errors. As shown in LM-ARCH tests, when the conditional heteroscedasticity is strongly presented in our data, the ECM is not sufficient tool the introduce to hedging strategy. The ECM-GARCH(1,1) model captures the phenomenon that the conditional relationship spot-future price is variable in time.

**Model 8: ECM-GARCH (1;1)**
using observations 2000-01-06–2014-09-17 ($T$ = 3835)
Dependent variable: r_S_t

| | Coefficient | Std. Error | $t$-ratio | p-value |
|---|---|---|---|---|
| const | 0.0145146 | 0.0211752 | 0.6855 | 0.4931 |
| r_F_t | 0.969240 | 0.00587246 | 165.0486 | 0.0000 |
| F_t_1 | 0.00276963 | 0.000184130 | 15.0417 | 0.0000 |
| F_t_2 | −0.00277177 | 0.000184154 | −15.0514 | 0.0000 |
| u_1 | −0.0555357 | 0.0254941 | −2.1784 | 0.0294 |
| r_S_t_1 | −0.160189 | 0.0176837 | −9.0586 | 0.0000 |

| | | | |
|---|---|---|---|
| Mean dependent var | 0.030785 | S.D. dependent var | 1.715329 |
| Sum squared resid | 1383.856 | S.E. of regression | 0.601178 |
| $R^2$ | 0.877328 | Adjusted $R^2$ | 0.877168 |
| $F(5, 3829)$ | 5476.885 | P-value($F$) | 0.000000 |
| Log-likelihood | −3487.129 | Akaike criterion | 6986.259 |
| Schwarz criterion | 7023.771 | Hannan–Quinn | 6999.584 |
| $\hat{\rho}$ | −0.191689 | Durbin–Watson | 2.383362 |

**GARCH(1,1)** - estimation

| | Coefficient | Std. Error | $z$ | p-value |
|---|---|---|---|---|
| const | 0.0276486 | 0.0212113 | 1.3035 | 0.1924 |
| $\alpha_0$ | 0.0221509 | 0.00599041 | 3.6977 | 0.0002 |
| $\alpha_1$ | 0.0652370 | 0.00743479 | 8.7746 | 0.0000 |
| $\beta_1$ | 0.927481 | 0.00818703 | 113.2866 | 0.0000 |

Resulting Model 8 has all the variables highly significant, error correction term is much smaller than in the simple ECM case, which seems to be much more reliable but still negative. The overall fit of the model is slightly worse than the single ECM case, on the other hand this model is still better than the adjusted $R^2$ of OLS and SE of the regression. In addition, the model is much more efficient than the GARCH family approach yet it uses error term methodology. Therefore we consider this approach as more rigorous and robust than simple ECM approach and we take the ECM-GARCH(1,1) hedging ratio 0.969 as the most suitable for reducing the risk when hedging with 3 months futures contract in LME copper market.

## 5.5 Comparison of Optimum Hedge Ratios

Table 5.7: Comparison of Optimum Hedge Ratios

| | OLS | ECM | ECM-GARCH | GARCH (1,1) | GARCH (2,1) | EGARCH (1,1) |
|---|---|---|---|---|---|---|
| **Beta** | 0.9626 | 0.9765 | 0.9692 | 0.9275 | 0.9052 | 0.98670 |
| **adj_R2** | 0.8667 | 0.8877 | 0.8773 | | | |
| **S.E.** | 0.626 | 0.575 | 0.601 | | | |
| **Akaike** | 7298.1 | 6649.3 | 6986.3 | 13928.3 | 13927.3 | 13940.6 |
| **Han-Quin** | 7302.5 | 6664.9 | 6999.6 | 13939.4 | 13940.6 | 13951.7 |
| **Schwartz** | 7310.6 | 6693.0 | 7023.7 | 13959.5 | 13964.8 | 13971.8 |

The cointegration tests found spot and future prices are being I(1) processes. Such findings suggest using the ECM methodology which should improve the inefficiency in the original OLS view. Further analysis reveals the optimal lag length equal to 2 and resulting OHR is 0.9765 which - supported by the model statistics - seems to be most reliable from all performed models. However, it is unable to capture the phenomenon of time-varying risk premium.

The GARCH approach and related time series analysis provided the evidence of residuals suffering from ARCH effects. Such findings serve as an extension to the violation heteroscedasticity and autocorrelation assumptions of the original OLS model. Therefore the GARCH approach is supposed to serve as much more robust and efficient tool in reducing the spot price risk. On the other hand, the reported statistics (almost double criterion values) shows, that ECM methodology is superior in the modeling performance.

Regarding the introducing hedging strategy to the EMC in Mongolia, ECM model suggests that if hedger uses this model, value of a futures contract to the value of the underlying asset is 0.9765 and it can give the best hedge effectiveness. On the other hand, when hedger wants to capture the market volatility since market reaction to bad news is greater than good news, ECM-GARCH gives a slightly smaller OHR of 0.9692 together with reduced hedge effectiveness.

Allover, author suggests ECM-GARCH (1,1) to use in hedging strategy for the company since it reflects the conditional heteroscedasticity which is found during the analysis of time series and also corrects for the inefficiency of previously used methods. Compared to ECM it has slightly lower hedging ratio and slightly worse performance, but it takes into account the time-varying conditional heteroscedasticity. Hence, it should lead to the spot position risk minimization for the copper market.

# Chapter 6

# Conclusion

In this research, we have studied copper futures market in London Metal Exchange (LME). For this purpose, we have employed four econometric models to test the Efficient Market Hypothesis (EMH) and to estimate Optimum Hedge Ratios (OHR).

Firstly, we have employed cointegration test and Error Correction Model (ECM) to find out whether the market is efficient or not. Results indicate that copper market is efficient only in long-run with 3 months futures contracts in LME. From the cointegration test, we could see that there is a forecasting power of spot prices from futures prices and existed risk premium in the market. ECM model implied that market is inefficient in short-run. Altogether we could conclude that EMH is rejected.

Secondly, regarding the comparison of OHR, we have computed 6 different ratios based on risk premium specification: Ordinary Least Square (OLS) model for no risk premium, ECM and ECM-GARCH models for constant risk premium and General Autoregressive Conditional Heteroscedasticity (GARCH) family models for time-varying risk premium. Regarding OLS regression result, there was violation of assumptions of classical linear regression models because of the time-varying distribution and dependency. Thus we assumed that OLS hedge ratio might under-estimate the value of the proportion of a position that must be hedged to the value of the entire position.

Since the cointegration test implied that market is efficient only in long-run with constant risk premium, we analyzed the situation further with ECM. In this case, ECM provided OHR with the best hedging performance and OHR was slightly larger in value and more efficient than the OLS.

For time-varying risk premiums, we employed GARCH(1,1), GARCH(2,1) and EGARCH(1,1). The GARCH approach provided the evidence of residuals suffering from ARCH effects. Such findings serve as an extension to the violation of heteroscedasticity and autocorrelation assumptions of the original OLS model. Therefore the GARCH approach is supposed to serve as much more robust and efficient tool in reducing the spot price risk. On the other hand, the reported statistics of AIC and SBIC showed that ECM methodology is superior in the modeling performance. Additionally, EGARCH(1,1) results showed that the time series is slightly more sensitive to the negative news and they create more volatility than the positive shocks.

In the last model we considered cointegration relationship between two series and conditional heteroscedasticity in a one row. Such methodology is done through the model ECM-GARCH(1,1). The ECM-GARCH(1,1) gave the second best hedging performance and implied that ECM model might overestimated the OHR as it can result in hedging a spot portfolio that is more than required to reduce risk since ECM doesn't consider the conditional heteroscedasticity.

Main purpose of this thesis was to give the empirically proven, reliable information about the copper market in LME and to suggest appropriate hedging strategy to the Erdenet Mining Corporation which currently trades only in spot market of LME. From the empirical analysis, author could say that market is inefficient in LME and it is better to introduce some hedging strategy in such market. Regarding the value of the proportion of a position that must be hedged to the value of the entire position, author suggests ECM-GARCH(1,1) model to use for the hedging performance if the company wants to capture the market volatility into the hedging strategy.

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# Appendix A

# Title of Appendix One

Table A.1: ARMA checkin - Diagnostic tests

| | **test statistics** | **value** | **p-value** |
|---|---|---|---|
| **Portmanteau** | Chi$\hat{2}$ | 36.5746 | 0.0005 |
| **Ljung & box** | Chi$\hat{2}$ | 36.6872 | 0.0005 |
| **Jarque-Bera** | Chi$\hat{2}$ | 2337.819 | 0.0000 |
| **skewness** | -0.2706 | **kurtosis** | 6.7860 |

Table A.2: ARCH-LM TEST with 5 and 10 lags for "GARCH Residuals"

| | GARCH (1,1) | GARCH (1,1) | GARCH (2,1) | GARCH (2,1) |
|---|---|---|---|---|
| | 5 lags | 10 lags | 5 lags | 10 lags |
| test statistic: | 4.7139 | 23.8384 | 14.1301 | 44.2517 |
| p-Value(Chi$\hat{2}$): | 0.4518 | 0.0080 | 0.0148 | 0.0000 |
| F statistic: | 0.9439 | 2.3988 | 2.8365 | 4.4769 |
| p-Value(F): | 0.4512 | 0.0078 | 0.0146 | 0.0000 |